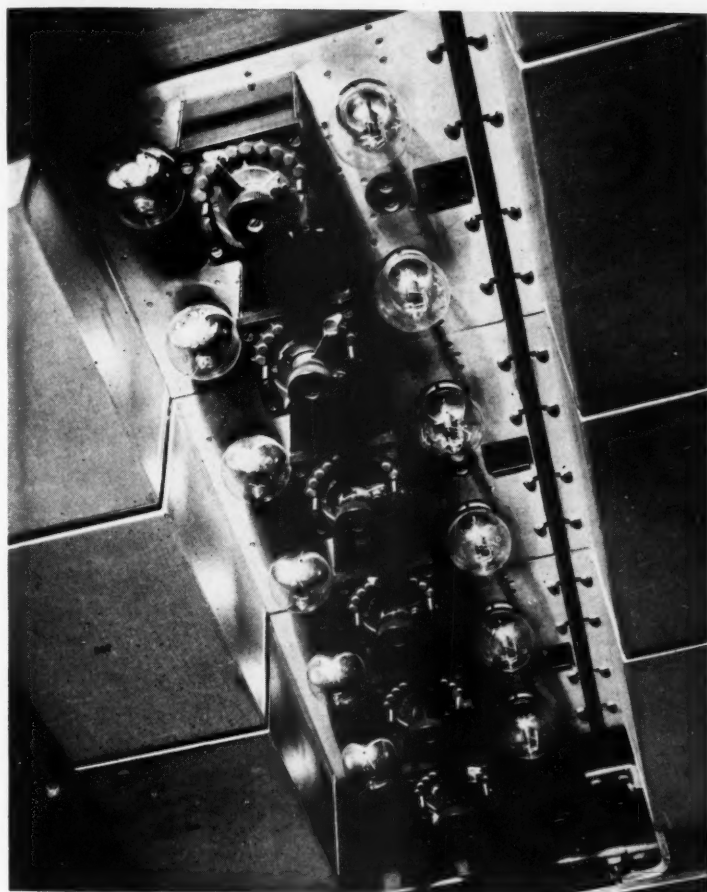


# BELL LABORATORIES RECORD



*A bay of telephone repeaters*

VOLUME FOURTEEN—NUMBER TEN

*for*  
**JUNE**  
*1936*

# Effect of Electric Shock on the Heart

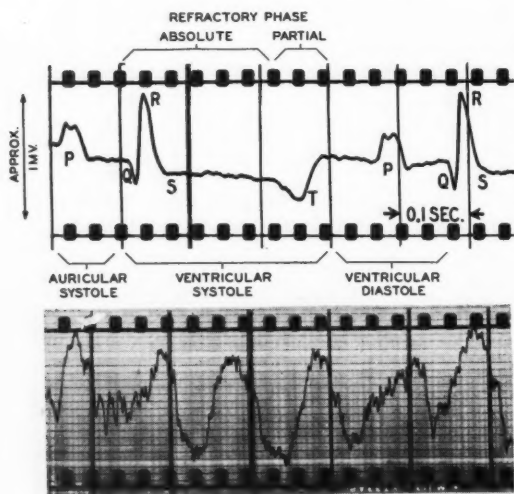
By L. P. FERRIS

Protection Development

**E**XPERIMENTAL investigations of the effects of electric shock on living things long antedate all commercial uses of electricity, but this work of the early experimenters left much to be desired, particularly in defining the limits of shock which are dangerous to man. As a basis for the development of protective measures and practices, such knowledge is obviously important. To obtain some of the needed data a joint investigation by the Department of Physiology of Columbia University and the American Telephone and Telegraph Company was initiated in 1927 and has since been continued

with the help of Bell Telephone Laboratories.\*

In seeking a value of current which if exceeded would be dangerous to man, it is important to consider for different practical conditions the effects which are brought about as the current is increased. The threshold of sensation is reached at about one milliamperere for a frequency of 60 cycles. Other investigators have found that with 15 milliamperes from hand to hand a subject is unable to release himself. Any currents which prevent voluntary control of the muscles are dangerous because their pathway might include the respiratory muscles and stop breathing. No serious or permanent after-effects are likely merely from the cessation of respiration, provided it is not continued beyond the point where the victim can be resuscitated by artificial respiration. Currents somewhat greater than those just necessary to stop breathing may derange heart action and cause fatalities even though the duration of such shocks is but a few seconds or less, far too short to be important from the standpoint of interruption



*Fig. 1—Electrocardiograms of sheep: Above—Normal, before shock. The letters are those used in medical practice to indicate the waves of the electrocardiac cycle. Below—Ventricular fibrillation after a severe electric shock has been received between the right foreleg and the left hind leg*

\*Drs. H. B. Williams and B. G. King of Columbia University have coöperated throughout this investigation with P. W. Spence of the Bell Laboratories and the author. The experimental work has been for the most part conducted in the Physiology Laboratories at the Medical Center by Mr. Spence, Dr. King and assistants. Mr. M. E. Strieby of Bell Laboratories participated in the early part of the investigation. A more detailed report of these studies entitled "The Effect of Electric Shock on the Heart" can be found in the May, 1936, issue of *Electrical Engineering*.

of respiration, and obviously too short to give any opportunity for rescue before the end of the shock. Death in these cases is brought about by ventricular fibrillation, in which condition the ventricular muscle fibers of the heart contract in an uncoordinated manner, twitching and quivering, in contrast to their normal coordinated rhythmic movement. As a consequence the pumping action of the heart ceases and the failure of circulation results in an asphyxial death within a few minutes. The medical profession has long recognized that when this condition is set up in man it is very unlikely to cease naturally before death. The value of current just under the threshold for fibrillation may, therefore, be taken as the maximum current to which man may safely be subjected, since, regardless of rescue or after-treatment, death is liable to result from greater currents. The experimental investigation described here was, for this reason, directed towards a determination of the variation of this threshold current with a number of factors which enter into the practical application of the results. A number of species of animals were included in the tests to establish the trend of the effects with variation in physiological and morphological factors, but most of the experiments were upon animals comparable in body weight and in heart rate and weight to man, so that the results which were obtained would be indica-

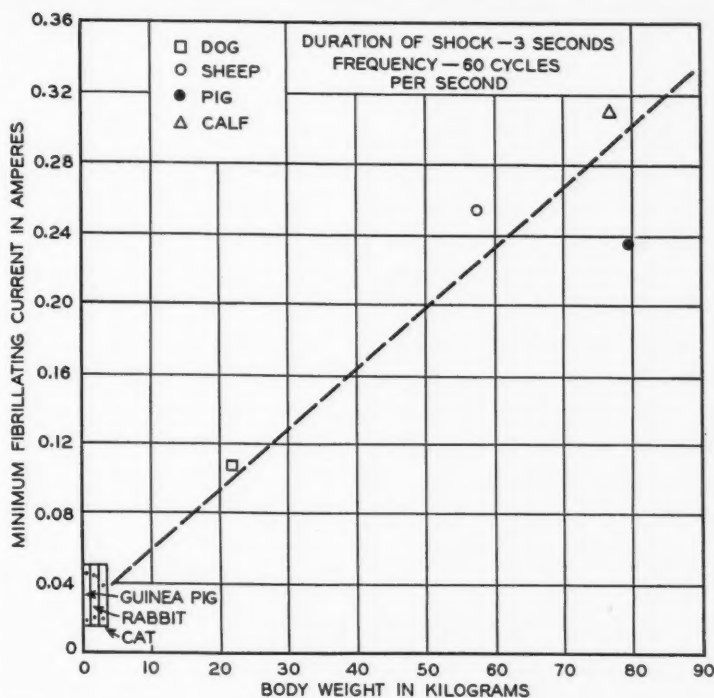


Fig. 2—The minimum current which will cause ventricular fibrillation is roughly proportional to the weight of the animal

tive of what might be expected in man.

The animals were kept under surgical anaesthesia during the tests and the behavior of their hearts was studied by making electrocardiograms of each animal before and after shock. These were recorded together with the shock current and voltage, by a three-string oscillograph. An electrocardiogram is a graphical record of the time variation of the voltage which is always associated with the action of the heart. A normal sheep electrocardiogram is shown by the upper part of Figure 1, while the lower part is an electrocardiogram of a sheep whose heart is in ventricular fibrillation.

The threshold currents required to cause fibrillation in seven different species of animals were determined under standard reference conditions which included the use of 60-cycle alternating current for a duration of 3 seconds, with electrodes on the

right fore and left hind legs—conditions typifying those of many accidental shocks to man. The general results are shown in Figure 2 in which the minimum fibrillating current is plotted as a function of the body

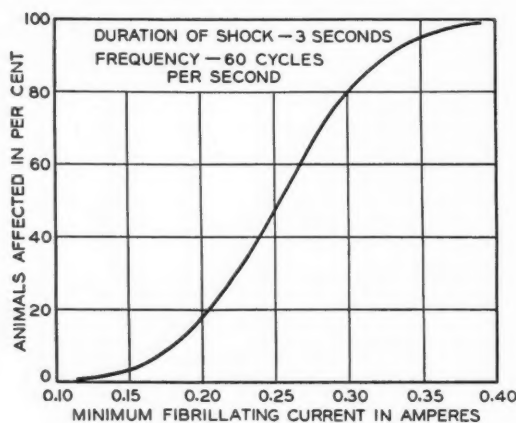


Fig. 3—The current required to produce fibrillation in sheep varies appreciably from one animal to another

weight of the different species. Individuals depart widely from the general trend of these results as is shown by Figure 3. The average weight of an adult man is approximately 70 kilograms and these results on the whole indicate that currents in excess of 0.1 ampere at 60 cycles, from hand to foot, will be dangerous for shock durations of 3 seconds or more.

Inasmuch as the path of the current through the body affects the proportion of current which reaches the heart, the current path as determined by the points of contact with an external circuit influences the amount of current necessary to cause fibrillation. Based upon the animal tests, it is concluded that for man, pathways from arm to leg, across the chest, chest to arm and head to leg, may be expected to give about the same threshold. The pathway between the arms should give a somewhat higher

threshold and from leg to leg the proportion of current reaching the heart is so small that fibrillation is not liable to result, even at currents of 15 amperes or more. Such currents would, however, probably burn or otherwise injure the victim, unless the contacts were good and the shock of short duration.

For shocks which last a second or more, the threshold fibrillating current at 25 cycles is about 25 per cent higher than the 60-cycle value and the direct current threshold about 5 times that at 60 cycles. This relation probably does not hold for shock durations of a small fraction of a second, in which case thresholds for these frequencies would be expected to approach one another.

For shocks whose duration might be limited by quick-acting circuit breakers or other protective devices to a small fraction of a second, it was expected that the effect would depend upon the phase of the cardiac cycle during the occurrence of the shock. In Figure 1 (top) the so-called "waves" of the electrocardiogram are lettered in accordance with common medical practice, and the different phases of the cycle are indicated. Special circuits were developed to take advantage of the conspicuous differences among the electrocardiac impulses of a single heart beat to initiate operations which controlled the application of the shock and the recording of the current, the voltage and the electrocardiogram. Figure 4 is a schematic diagram of the apparatus employed for this purpose. By proper timing and biasing, the marginal tripping circuit operated only on the QRS wave. The timing of the shock in relation to this reference point was regulated by an adjustable electrical delay circuit and the duration of the shock was controlled by



another similar circuit. The feeble impulses of the heart itself were thus made to control the power switches which applied the shock. The oscillograph was started a few seconds before shock and operated continuously, recording the pre-shock electrocardiogram, oscillograms of shock current and voltage, and a post-shock electrocardiogram of sufficient duration to show the effect of the shock on the heart. The exact time relation of the shock to the immediately preceding electrocardiac cycle can thus be determined, assuming only that the heart continued its normal beat for the fraction of a second between the disconnection of the cardiograph and the application of shock. Typical records obtained in these tests are shown in Figure 5. Time lines appear ten times a second. The upper record of Figure 5 A shows a shock followed by a coordinate heart beat, while the lower record, B, is of a shock which resulted in ventricular fibrillation. The action currents from the body muscles which persist after the powerful muscular contractions during the shock obscure to some extent all post-shock electrocardiac records, making them appear to have high-frequency irregularities, but the post-shock portion of Figure 5 A reveals the same typical sequence of prominent deflections which appear before shock, proving coordinate heart action. As a result of giving over 1,000 such controlled shocks to sheep, it was discovered that in order to produce fibrillation, shocks of 0.1

second or less must occur during the partially relaxed period of the cardiac cycle, corresponding to the T-wave of the electrocardiogram. This sensitive phase of the cardiac cycle is about twenty per cent of the whole. Outside of it fibrillation cannot be produced, with extremely rare exceptions, by currents up to at least 15 amperes, which was about the limit

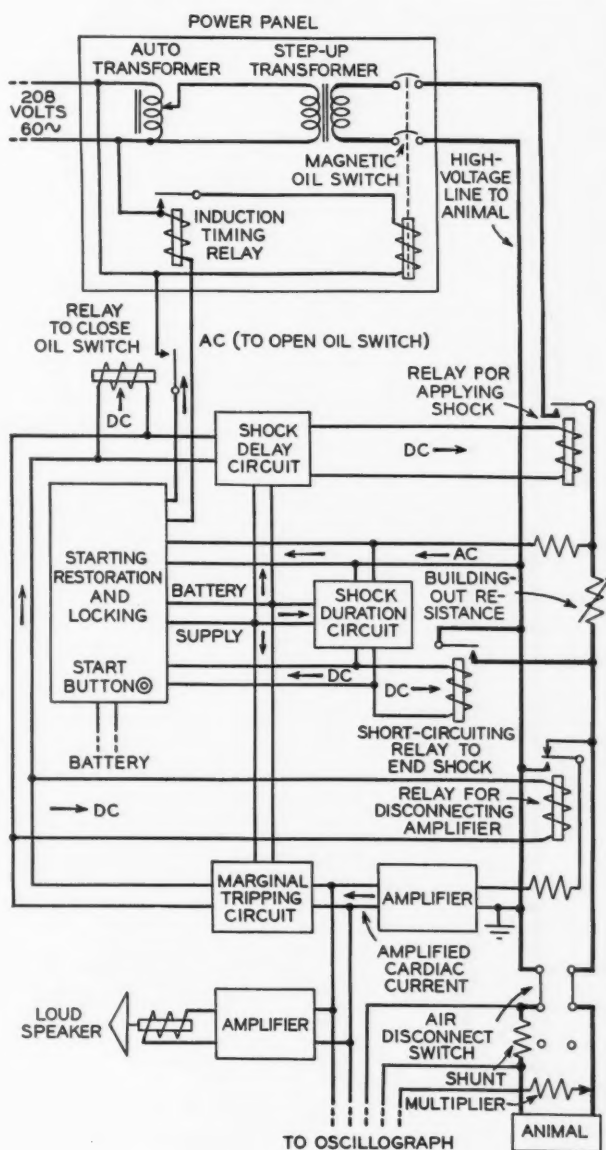
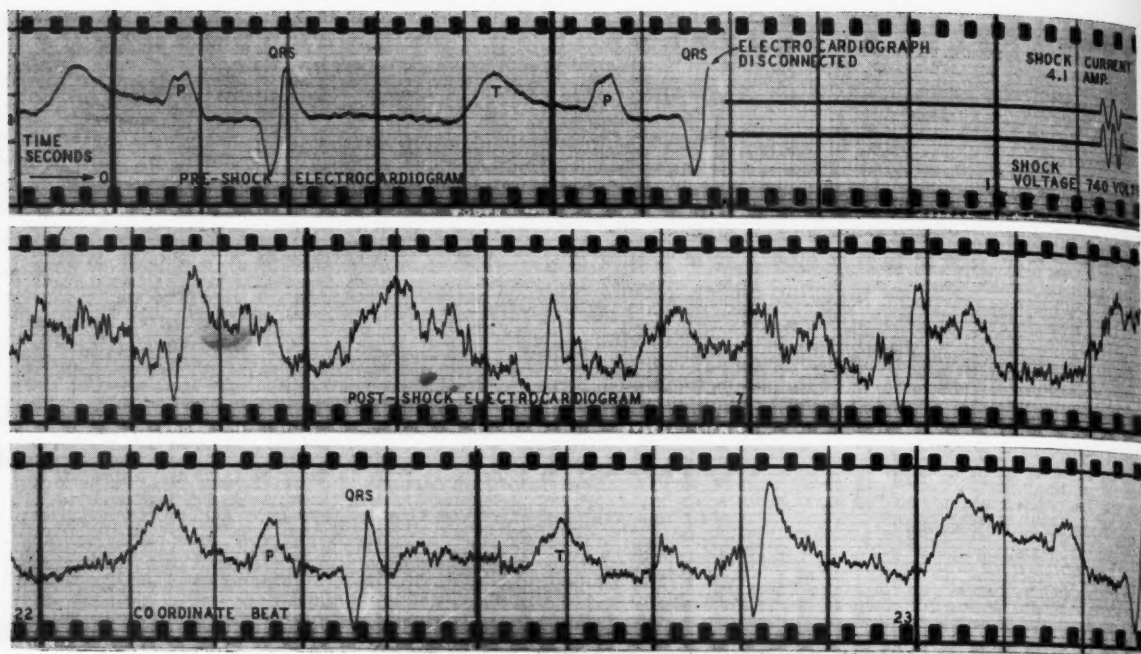
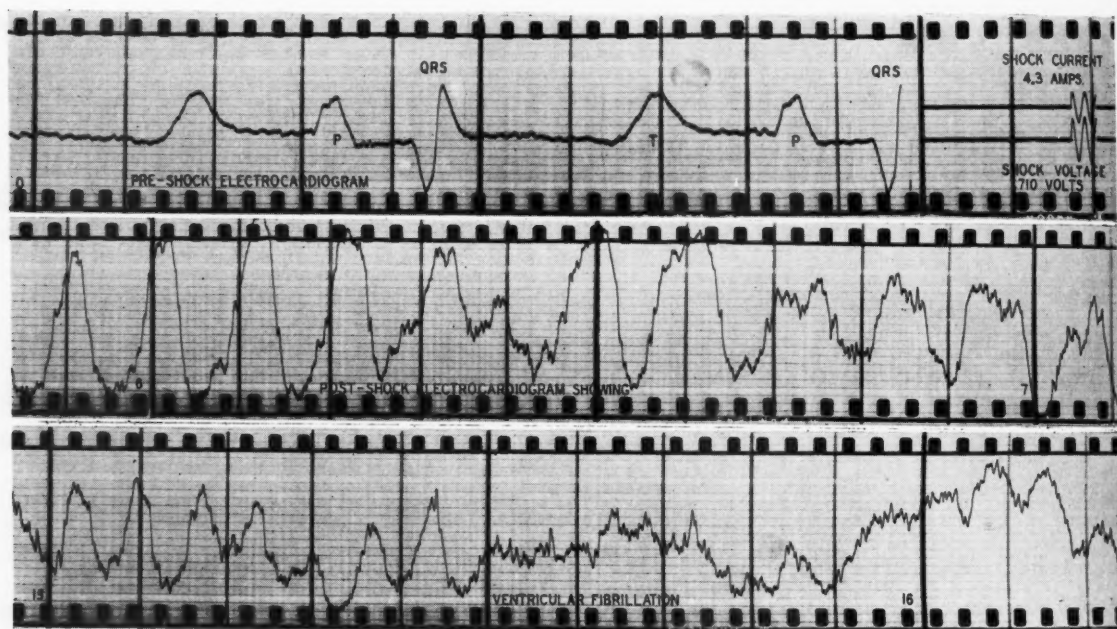


Fig. 4—Diagram of the apparatus used for applying shocks at predetermined points of the heart cycle



A



B

Fig. 5—Typical records of 0.03-second shocks to sheep: Top Group—during insensitive phase of cardiac cycle. Bottom Group—during sensitive phase of cardiac cycle. The electrodes were fastened to the right foreleg and left hind leg

of the tests which were carried out.

With the discovery of the sensitive phase of the heart cycle the threshold current required to produce fibrillation for short duration shocks was then determined. It is seen in Figure 6 that the threshold current varies inversely with shock duration, but not uniformly—being most sensitive to change as the duration approaches the time of one heart beat. For shocks of 0.1 second or less it is ten or more

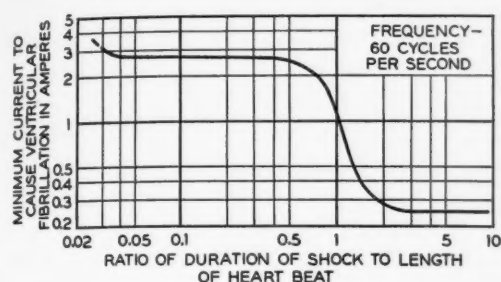
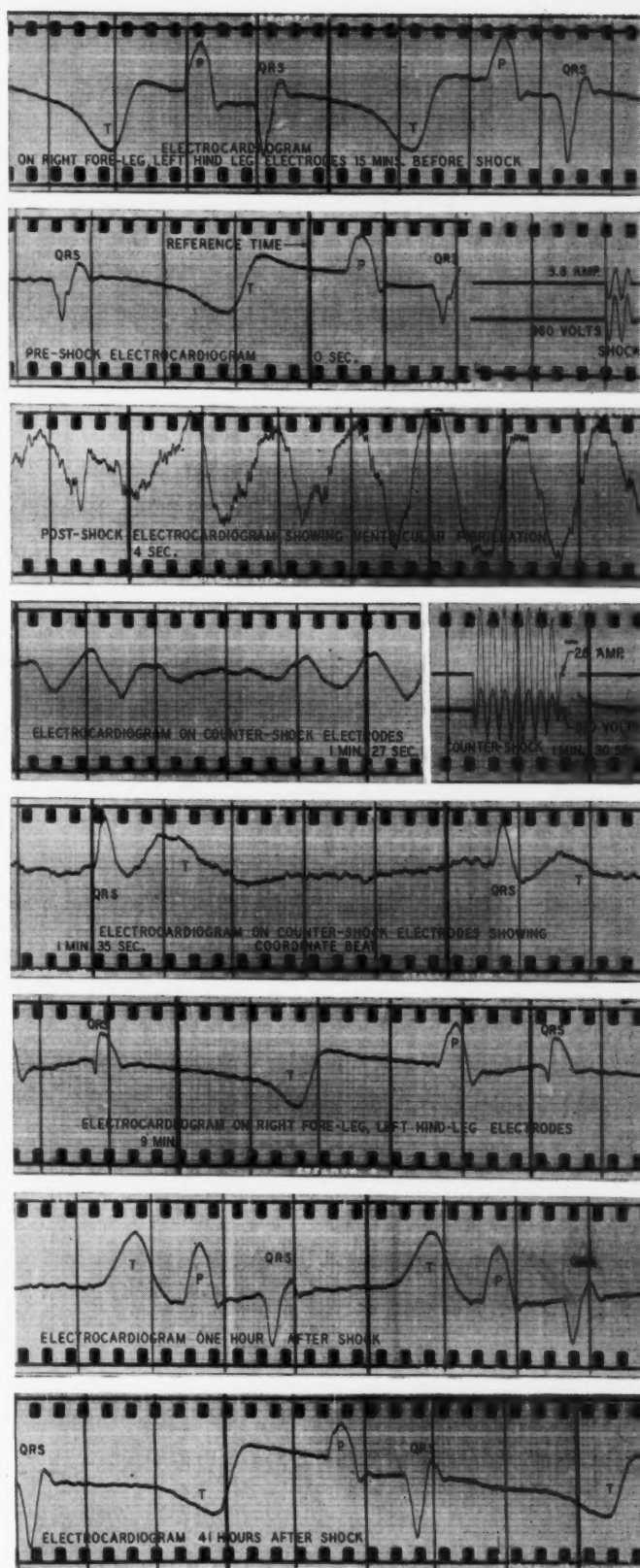


Fig. 6—Considerably greater current is required to cause fibrillation if the shock is of very short duration

times the threshold for durations of one second or more—a fact of great importance in the development and application of protective devices and methods.

Shocks a third or more of the heart cycle in duration may cause fibrillation, even though they would not extend into the sensitive phase of the cycle if the heart continued its normal beat. The reason is probably the initiation of a premature heart beat which brings about a premature sensitive phase prior to the end of the shock.

Fig. 7—Right: Record of restoration of sheep heart from ventricular fibrillation by a countershock. Electrocardiograms taken immediately preceding shock, immediately after shock showing ventricular fibrillation, and at intervals following countershock. The latter records show the progressive development of normal heart beat



The susceptibility of the heart to fibrillation by short shocks increases with current up to several times the threshold as might be expected, but then the liability of fibrillation, strange as it may seem at first sight, diminishes and becomes very small for currents of the order of 25 amperes through the body in the vicinity of the heart. However, other serious injury may be expected from such currents when brought about by accidental contacts.

More surprising even than the fact that high currents are less prone to produce fibrillation than low currents, is the fact that fibrillation once caused by a relatively low-current shock can be arrested and the heart action brought back to normal by a subsequent electric shock of high intensity and short duration through the heart. This seems to be a rather striking and true example of the old adage that "The hair of the dog is good for the bite." In the experimental study of the threshold conditions which bring about fibrillation, this normally fatal effect was necessarily the end result of most of the tests and an opportunity was thus afforded to investigate the effect of this so-called countershock method of restoring heart action. The method was first reported by the physiologists Prevost and Battelli,

who worked at the University of Geneva in 1899 on dogs and smaller animals. In the investigation reported here, the method was successfully applied not only to dogs, but to sheep, hogs and calves. A record of the restoration of a sheep's heart from ventricular fibrillation by countershock is shown in Figure 7.

To be successful, a countershock must be administered promptly after the fibrillating shock, probably within a few minutes. The need for maintaining respiration by artificial means is in no way lessened. In fact, the administration of artificial respiration even in the interval before the application of a countershock is highly advisable, not only for respiration itself, but because of the accompanying slight circulation which will assist in the nutrition of the heart and delay the degeneration of the brain. Because our experiments using an arbitrarily chosen countershock on animals comparable in size to man showed a successful restoration in about sixty per cent of the cases, we can conclude that the method of countershock has distinct possibilities of successful application to man. The optimum conditions of countershock and practical apparatus and techniques for its application are matters which can only be determined by further work.





## High-Fidelity Radio Broadcasting

By E. L. OWENS

*Radio Development Department*

**I**F a broadcasting system performed its function perfectly, it would serve only as a medium for converting sound into electrical energy so that it could be transmitted through the ether with no form of distortion. Nothing would be omitted from the sounds picked up, nor would anything be added to them. More specifically this means that all the component frequencies of the program would be transmitted at their true relative volumes, and that no additional energy in the form of noise or other disturbances would be added. For a listener to obtain the maximum benefit from high fidelity broadcasting, his receiving equipment, of course, would have to be capable of

a precisely equivalent performance.

Since the quality of the transmitter's output depends chiefly on the frequency range, the volume range, and the amount of harmonic distortion, these three characteristics may be used to gauge the fidelity of a transmitter. A high-fidelity transmitter is one that approaches near enough to perfection to make the programs reproduced by a suitable receiver enough like the original to be satisfactory to a critical listener. The requirements for a high-fidelity transmitter would vary with the type of program to be transmitted. For perfect reproduction of music, all frequencies from about 40 to perhaps 15,000 cycles would have to be transmitted equally. The very

high frequencies, however, are required for only a few of the musical instruments, and since they are present only in small volume, and are not detected at all by some people, an upper frequency limit of 8000 cycles is taken as meeting the high-fidelity requirements under present conditions.

Volume range also varies with the type of program. The range of sound power of a large symphony orchestra may be of the order of ten million to one, or 70 db. For smaller orchestras or single instruments this range would be much less. The limiting factors of volume range in the transmitter are the load carrying capacity of the equipment at the upper end, and the noise level at the lower, since the noise must be lower in level than the weakest sound to be transmitted. Noise, which includes all unwanted frequency components that would be reproduced with the program, is objectionable chiefly to the extent that it interferes with the received program. The amount of this interference depends not only on the magnitude of the noise currents but on their frequency. Research work carried on in

these Laboratories has determined the relative disturbing effects of noise at all frequencies.\* In general it is of much less importance at low frequencies and at the very high frequencies. For this reason the only satisfactory way of measuring noise in a broadcasting circuit is by use of a weighting network which automatically corrects the noise at various frequencies to conform to its actual effect on reception.

From the standpoint of reception, the usable volume range depends upon a number of external factors, such as room noise and static disturbances. Because of this situation, a weighted noise level 40 db below the signal at 100 per cent modulation would result in as high a fidelity as would generally be usable by the listener. To merit a high-fidelity rating, however, the transmitter should be capable of better performance than this, so as not to contribute to the noise level when receiving conditions are good.

Harmonic distortion in broadcasting equipment is caused by the non-linearity of certain elements in the

\*RECORD, March, 1936, p. 233.

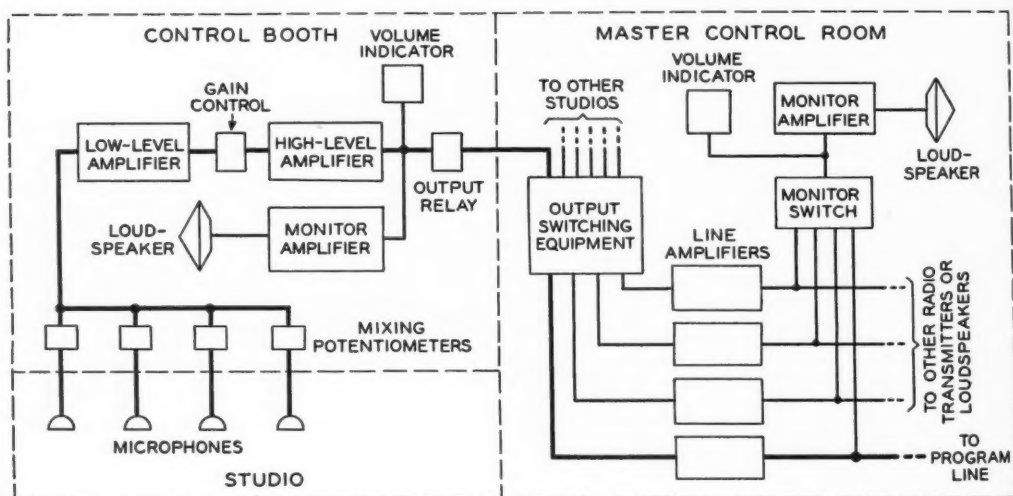


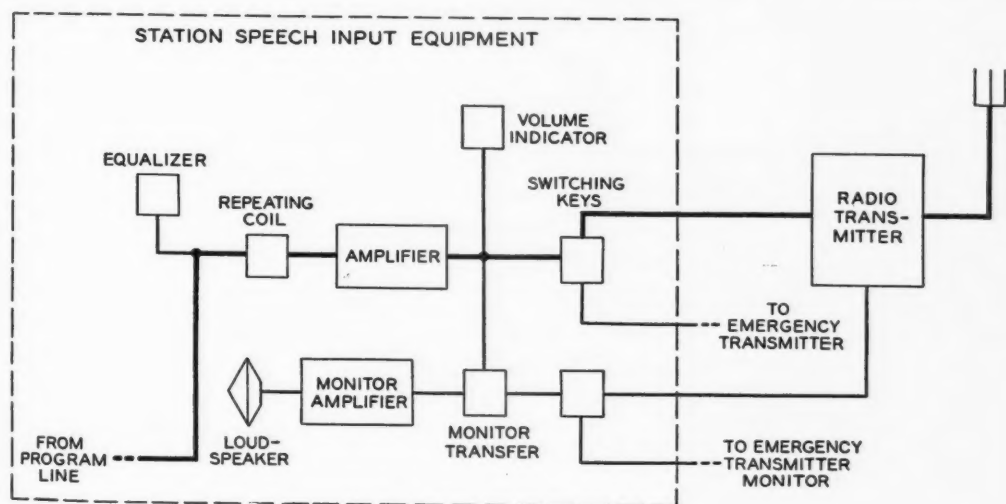
Fig. 1—Schematic layout of a

system, which results in the introduction of frequency components not present in the original. Since these components are harmonics of lower ones, their effect becomes more pronounced as the frequency band is widened. For high-fidelity programs these harmonics should not exceed 5 per cent for peaks of modulation approaching 100 per cent since amounts in excess of 5 per cent cause distortion that can be readily detected. This value should decrease for lower levels and should not exceed 2 per cent at 30 per cent modulation. To keep the harmonic distortion below these values requires a careful design and adjustment of all component parts of the system.

These various suggested requirements for high-fidelity broadcasting have, of course, no official standing, and to some extent are arbitrary, but any station meeting them could be said to have high-fidelity characteristics according to present-day standards.

A broadcasting system, to meet the above requirements for high-fidelity transmission, requires careful design

and engineering of the entire system considered as one coördinated unit from microphone through studio speech input equipment, master control room, program wire circuits, station speech-input equipment, and radio transmitter. In the past it has sometimes been assumed that when units that were individually satisfactory from a transmission standpoint were installed and connected together in a high fidelity system, their operation would be satisfactory from an audio-frequency standpoint without the necessity of making overall measurements on the system. While this might be considered a logical assumption when high quality units make up the system, it does not take into consideration the fact that due to the complexity of a modern broadcasting system and the number of units involved, the cumulative effect of small variations in the characteristics of amplifiers and repeating coils, small capacitances in inter-unit wiring, or slight impedance mismatches in mixing circuits, amplifier coupling circuits, and line-terminating equipment may cause the overall frequency characteristic to



fall far short of the desired performance. Such effects can be detected and isolated only by complete overall measurements as well as by measurements of all of the individual sections of the system.

Station WOR, owned and operated by the Bamberger Broadcasting Ser-

equipped with Western Electric moving-coil microphones, and each has an associated control booth from which the operator has a view of the studio through a plate glass window. Each of these booths is equipped with a control unit on which is mounted the microphone mixing potentiometers,

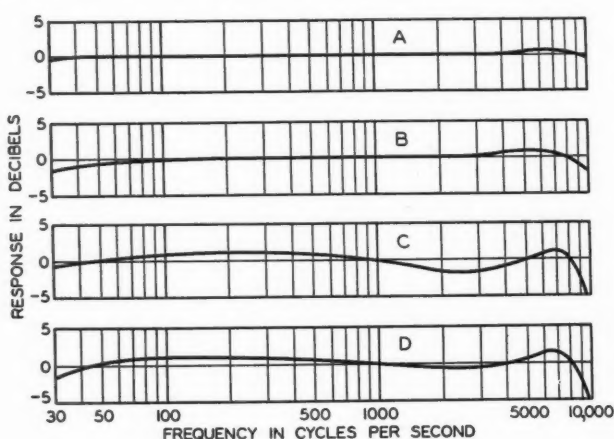


Fig. 2—Frequency characteristics of various sections of the WOR system: A—studio alone, B—studio and master control room, C—transmission line and speech input equipment at transmitter station, and D—overall characteristic of the complete system

vice, is the first high-power radio station to meet all the requirements for high-fidelity broadcasting as outlined above. This new 50 KW transmitter, located at Carteret, N. J., was developed by the Laboratories and manufactured by the Western Electric Company. The transmitting station has already been described in the RECORD.\* All programs for Carteret pass through a master control room in New York which is supplied from ten studios located in New York and Newark.

Most of the programs originate in the New York studios, which are of various sizes so as to accommodate any program from a single speaker to a large symphony orchestra. All are

\*RECORD, April, 1935, pp. 226 and 232.

Low-level mixing circuits have been used throughout the system. The output of the mixing circuit in each control booth is connected to the input of the low-level amplifier, and the master gain control is located in the circuit between the low-level and high-level amplifiers. All studio amplifiers are completely a-c operated. The vacuum tube filaments are heated directly with alternating current, and the plate voltage for the tubes is obtained from a rectifier through a filter of suitable design. The high-level amplifiers in the control booths terminate in an output switching circuit in the master control room, so that the outputs of one or more studios may be connected to the line amplifier that supplies the program to the radio transmitter. An equalized 16-gauge non-loaded

equipped with Western Electric moving-coil microphones, and each has an associated control booth from which the operator has a view of the studio through a plate glass window. Each of these booths is equipped with a control unit on which is mounted the microphone mixing potentiometers, the master gain-control switching keys, and a volume indicator, and each has an amplifier bay. This latter bay includes both low-level and high-level amplifiers and associated power equipment, a meter for measuring amplifier plate currents, a jack panel, and a line equalizer for incoming program lines from remote pick-up points. A high-quality loud speaker is included in each booth for aural monitoring. All of these studios are in use most of the time; one actually broadcasting and the others being used for rehearsals.

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cable circuit connects the master control room with the speech-input equipment at the Carteret station.

In the final adjustment of this system tests were made of the various sections as well as overall from microphone to radio-transmitter output. Some of the frequency characteristics are shown in Figure 2. Curve A is from the microphone input circuit of Studio No. 1 to the output of the booth amplifying equipment, while Curve B shows the overall characteristic from the microphone input circuit to the output of the master control room. It will be noticed that for the studio itself the characteristic is flat to within  $\frac{1}{2}$  db from 30 to 10,000 cycles. The overall characteristic to the output of the master control room is about as flat over most of the range although it drops off slightly at the upper and lower ends, but even at 30 and 10,000 cycles it is down less than 2 db. This section includes all switching circuits, gain control attenuators, and both low-level, high-level, and line amplifiers, with a gross operating gain of 116 db, or nearly a million millionfold increase in power. Harmonic distortion in this section is well under one per cent.

Curve C shows the characteristics of the transmission line from New York to Carteret combined with the speech-input equipment at the radio-transmitter station. It is flat to within 2 db from 30 to 9000 cycles. The overall characteristic, from the microphone input terminals in New York to the output of the radio transmitter at Carteret, is shown by Curve D. This also is flat to within 2 db over the same range of frequency.

The total harmonic distortion at the output of the radio transmitter

is shown in Figure 3 for levels from 30 per cent to 100 per cent modulation and with a pure 400-cycle signal. The weighted noise level of the entire system, including the radio trans-

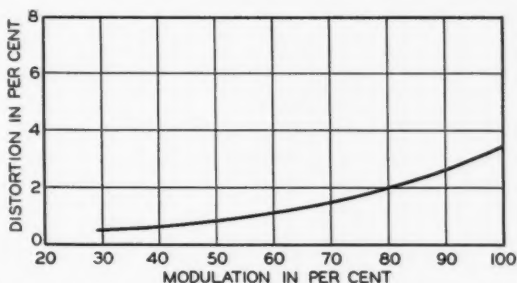
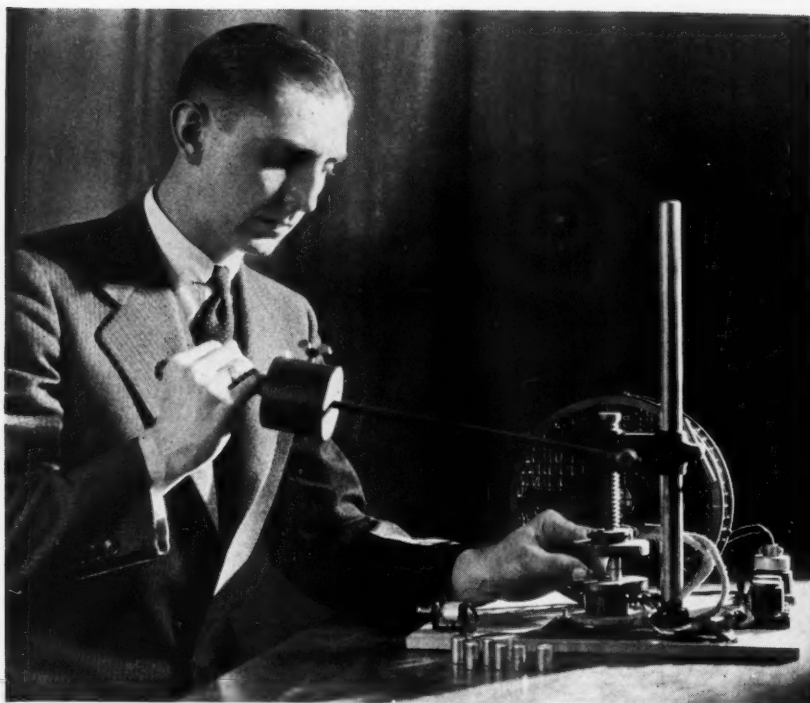


Fig. 3—Harmonic distortion characteristics for broadcasting station WOR

mitter, the station speech-input equipment, the program line to New York, and the studio speech-input equipment is 62.5 db below the signal at 100 per cent modulation. With such a noise level, it is obvious that the volume range of the system will well meet the 40 db mentioned as a requirement. This is a somewhat greater volume range than is broadcast by most stations at the present time.

High-fidelity operation imposes considerable responsibility on the station personnel, since to secure continuously satisfactory performance frequent checks must be made of all operating characteristics. More careful monitoring on programs is also required, since over-modulation of the radio transmitter will ruin the quality of any radio program no matter how high grade the equipment may be. By proper attention to these operating procedures, WOR's new system is capable of the best that modern broadcast service permits, since the characteristics of the system well meet the high-fidelity requirements listed above and are superior to them in most respects.



## Adhesives

By JOHN B. DeCOSTE  
*Chemical Laboratories*

ADHESIVES are used in many different types of telephone equipment because cementing parts together is a simple method of construction which is often preferable to any other process. Adhesive joints are not only light in weight and occupy a negligible amount of space but many times their use permits an assembly which otherwise could not be made. Moreover, recent improvements in adhesives have so greatly increased their strength that it is now possible to realize tensions of one-half ton per square inch in air-dried joints, and of almost a whole ton where the adhesive is applied dry and then melted by heat. When properly selected they will produce joints which will withstand tempera-

tures and humidities safely above those at maximum summer conditions.

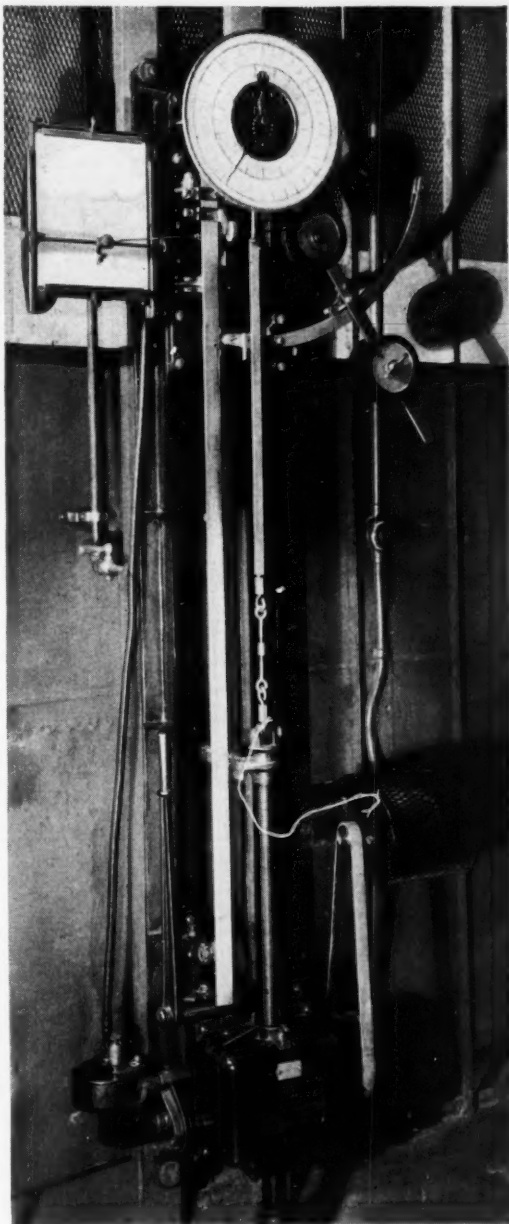
Adhesives are for the most part organic in nature and may be divided into two classes: the agglutinous, which includes animal glue, casein, dextrin, and gum arabic; and the resinous, such as the vinyl and alkyd resins, the natural resins such as rosin and shellac, the varnishes, and pyroxylin cements. The agglutinous adhesives are water soluble and are characterized by poor electrical insulation and moisture resistance. Their use is chiefly confined to parts of the telephone plant which are remote from electrical circuits. The resinous adhesives on the other hand generally have good insulation and moisture resistance, which render

them particularly valuable in the assembly of telephone equipment.

There are two methods of using adhesives to make a joint. The one most commonly employed is to disperse the adhesive in a suitable solvent and apply it to one or both surfaces, which are then pressed together while the adhesive is still wet. The joint is then allowed to dry in the air at room temperature, although mild heat may be applied if desired to accelerate the drying process. The other method is a process in which sufficient heat is used to melt a dry thermoplastic adhesive previously placed between the surfaces to be joined. Various processes are possible which differ mainly in the way the thermoplastic adhesive is carried to the surfaces. For this purpose powdered resins, adhesive tissues, stick adhesives, or thermosoftening resin solutions are used. The thermoplastic method has the advantage that parts to be joined may be coated with adhesive in advance and assembled at a subsequent time. It is also possible to make joints quickly and easily with excellent uniformity of strength. A limitation of the thermoplastic method is that the parts joined must not be exposed in service to temperatures high enough to resoften the joint.

The mechanism of adhesion depends upon the nature of the surfaces joined. It involves two principles of which the most common is represented by joints of porous materials such as wood, paper, or fabrics. The adhesive penetrates these surfaces and, on hardening, anchors itself to their irregularities. This is called "mechanical adhesion." The other mechanism is represented by joints of impervious and smooth materials such as glass or metal. This may be termed "molecular adhesion"

and is only partly understood. Actually the two types of adhesive action operate in all joints with one or the other exerting the predominating influence. Pure cases illustrating either one of these mechanisms of



*Adhesive strength is determined by measuring the force which is required to pull apart the adhesive joint of a test specimen*

adhesion probably do not exist.

Molecular adhesion is a very interesting phenomenon. A suitably chosen adhesive will adhere to a highly polished surface without any visible means of support. The accepted explanation is that a preferred orientation takes place among the adhesive molecules due to surface forces which are probably of an electrostatic nature. This orientation of the molecules of an adhesive at a joint interface is essential in producing molecular adhesion, but it is also important that every adhesive material have powerful cohesive forces operating inside the substance, otherwise the adhesive will rupture within itself, and the joint thereby fail. For this reason it is generally advisable to use adhesives in as thin a layer as is practical in order to minimize the setting up of internal strains in the adhesive layer when it solidifies. In selecting base materials for use in adhesive compounds the more brittle substances are usually avoided. Sometimes plasticizing agents are incorporated to increase the flexibility of the adhesive.

Resinous substances are extremely complex in their structure and their adhesion is therefore difficult to study in a fundamental way. However, some insight into molecular adhesion has been gained by using pure simple organic compounds as adhesives. These are melted between flat surfaces of various materials and allowed to solidify by cooling, after which the adhesion is measured by determining the load required to rupture the joints in tension. Although the relationship between adhesion and chemical structure is not completely understood, no adhesives which adhere strongly to metals have been found among the non-polar (chemically symmetrical)

substances, whereas strong joints have been obtained with several polar (chemically unsymmetrical) compounds. For example, the joint strength of naphthalene which is non-polar, is only 25 pounds per square inch on copper, whereas that of alpha naphthol and alpha naphthoic acid, two polar derivatives of naphthalene, are above 300 pounds. The relative importance of polar groups has not yet been determined but in many cases it has been shown that the presence of hydroxyl (-OH) and carboxyl (-COOH) groups is a great aid in obtaining strong joints, particularly with the cyclic organic compounds. These results are in accord with the orientation theory of adhesion. Polar compounds because of their unsymmetrical structure would have the possibility of orienting themselves preferentially while the symmetrical non-polar compounds would be limited in this regard.

An idea is often advanced that adhesives adhere to metal surfaces by first visibly etching them in order to secure a mechanical bond. This idea was investigated by comparing the adhesion obtained on gold with that obtained on the more chemically active surfaces of copper, steel, and aluminum. The joint strengths were of the same order in each case, which indicates that on these metals at least there is no necessity for an adhesive to etch the surface in order to obtain a good hold.

Further knowledge of the physical and chemical properties of adhesives and an understanding of the mechanics of adhesion are needed because of the importance of these materials and the wide variations in their characteristics. No adhesive has as yet been compounded which is suitable in all types of joints.



## News of the Month

ON APRIL 13 Professor J. H. Van Vleck of Harvard University was a guest of the Colloquium and spoke on the subject *Recent Developments in the Theory of Magnetism*. After briefly discussing para- and dia-magnetism of gases, he considered the paramagnetic susceptibility of rare earth salts. Professor Van Vleck also discussed the theoretical and experimental work on the gyromagnetic ratio.

R. O. GRIDDALE spoke on *Non-Ohmic Conductors* at the April 27 meeting of the Colloquium. Non-ohmic conductors were defined by Mr. Grisdale as systems through which the current increases more rapidly than the applied voltage. It has been found that no homogeneous solid possesses an electronic conductivity of this type except at very high potential gradients. There are systems, however, which exhibit such conduction for low applied potentials, and he dealt particularly with such systems.

THE COMMUNICATION GROUP of the New York section of the A. I. E. E., April 16, was addressed by Dr. F. B. Jewett on the subject *Broad Band Transmission*. On May 4, Dr. Jewett attended the annual dinner of the Division of Engineering and Industrial Research of the National Research Council and spoke on the work of the Science Advisory Board.

E. T. MOTTRAM visited Hawthorne in connection with the development of new recording equipment.

THE SPRING CONVENTION of the Society of Motion Picture Engineers, held in Chicago from April 27 to 30, was attended by T. E. Shea, P. H. Pierce and G. Puller. Mr. Pierce presented a paper, *Photoelectric Cells and Their Method of Operation*, prepared by T. E. Shea, M. F. Jameson and himself. Mr. Puller presented a paper entitled *A High-Quality Reproducing System for Small Theatres*. While in Chicago

Mr. Pierce attended a committee meeting of the American Railway Association.

O. W. TOWNER supervised the installation of the one-kilowatt Western Electric radio transmitting equipment for The Outlet Company at Station WJAR, located at Providence.

ON APRIL 27, H. D. Wilson, R. C. Newhouse, W. A. Woods, R. M. Pease and J. G. Nordahl of the Radio Development Department, together with pilot A. R. Brooks, co-pilot P. D. Lucas and mechanic R. J. Zilch, flew to Washington, in the Laboratories Ford airplane. At Washington they demonstrated airplane radio equipment to Navy personnel.

J. W. SMITH recently returned from a trip to the West Coast where he has been coöperating with the U. S. Navy on radio tests.

E. M. MATTHEWS and R. M. C. GREENIDGE, with T. J. Maitland of the Long Lines Department and F. C. Buerk of the Operating and Engineering Department of the American Telephone and Telegraph Company, made a field trip to inspect the finish on underground loading-coil cases in the Morristown, New Jersey, area.

A. C. WALKER and M. BROTHERTON were at the Pittsfield plant of the General Electric Company to discuss the manufacture of high-voltage condensers known as Pyranol.

P. NEILL spent a week in Kearny in attendance at the Quality Survey conference on jacks.

F. HARDY and E. S. SAVAGE visited Kearny to discuss problems in the manufacture of protectors.

C. E. NELSON went to Westport, Connecticut, and Newark, New Jersey, on maintenance problems of step-by-step offices.

J. W. KENNARD of the Outside Plant Development Department and R. C.

Silvers of the Operation and Engineering Department of the A. T. and T. Company were at Fort Worth, Texas, for the start of reconstruction work on an open-wire line on which several pairs are being respaced to six inches and retransposed for cross-talk tests at twelve channel-carrier frequencies. They also visited St. Louis, Denver and Chicago in connection with open-wire and aerial-cable problems.

M. B. LONG and L. P. BARTHELD are in Dallas at the Texas Centennial Exposition in connection with the Bell System Exhibit which was planned in



*M. B. Long*

Bell Telephone Laboratories. Mr. Long, who has been responsible for most of its details, is supervising the installation and decorations of the exhibit; and Mr. Bartheld, who has acted as equipment engineer for its technical features, is helping to train the maintenance men in the group which will operate the equipment. The electrical equipment for the exhibit was constructed in these Laboratories. The architectural work and decorations are being done by the Diorama Corporation of America; and the air-conditioning equipment is being handled by the Westinghouse Electric and Manufacturing Company. The Southwestern Bell Telephone Company will operate the exhibit when the Exposition opens on June 6 with Douglas Williams, Advertising Manager, in charge, assisted by G. A. Dyer. The installation of the equipment

is also being carried out by the plant men of the Southwestern Company.

THE MANUFACTURE of coin collectors was discussed by J. M. Melick with engineers at Hawthorne.

C. S. GORDON and F. F. FARNSWORTH inspected manufacturing facilities for the production of electrolytic zinc coatings at the Johnstown, Pennsylvania, plant of the Bethlehem Steel Company. Mr. Gordon was also in Baltimore and Pittsburgh relative to the development of insulated wire.

G. Q. LUMSDEN and R. E. WATERMAN recently made an examination of wood specimens, treated with various preservatives, that are under test at Gulfport, Mississippi. They also visited Charleston, South Carolina; Shreveport, Louisiana; Texarkana, Texas, and Brownville, Alabama, to obtain additional specimens for installation in test plots.

C. H. AMADON was recently in Newark, Trenton, Camden and other points in New Jersey assisting with the instruction of pole inspectors for the New Jersey Bell Telephone Company.

W. J. THAYER spent two weeks in Hawthorne discussing the manufacture of the combined hand-telephone set.

R. L. GERUSO testified before Assistant District Attorney Jacobs of King's County on April 2 and 3 concerning data he had prepared in connection with the "key check" investigation.

THE EDWARD G. BUDD Manufacturing Company in Philadelphia was visited on April 22 by H. C. Atkinson, J. R. Townsend and L. E. Abbott to observe welding methods employed by this company. On April 29 and 30, Mr. Atkinson and Mr. Townsend visited the Army Experimental Station at Dayton, Ohio, and the Aluminum Company of America at New Kensington, Pennsylvania, in connection with a survey now in progress of welding methods and design for aluminum alloys.

W. J. FARMER was at the Kearny plant of the Western Electric Company to observe extrusion of detinned lead sheath.

THE SEMI-ANNUAL convention of the Electrochemical Society was held in

Cincinnati from April 22 to 25. K. K. Darrow presented the Joseph W. Richards Memorial Lecture of the Society, his subject being *Electricity in Gases*. R. M. Burns and H. E. Haring gave a paper, *The Corrosion Behavior of Painted Iron and the Inhibitive Action of Paints*. Mr. Burns was re-elected treasurer for the coming year.

PAPERS ENTITLED *Analysis by Internal Electrolysis* by B. L. Clarke, L. A. Wooten and C. L. Luke and *Paper as a Medium for Analytical Reactions*, by B. L. Clarke and H. W. Hermance, were presented by Mr. Clarke at the Spring convention of the American Chemical Society held in Kansas City. Mr. Clarke was elected president of the New York-New Jersey section of the Microchemical Division of the Society for the 1936-1937 year.

H. G. ARLT was in Pittsburgh in connection with the flood damage at the Sterling central office. He then visited the

Hawthorne plant to discuss general finishing problems with engineers there.

S. O. MORGAN attended a meeting of the Physics Subcommittee of the National Research Council Committee on Insulation, held in Washington.

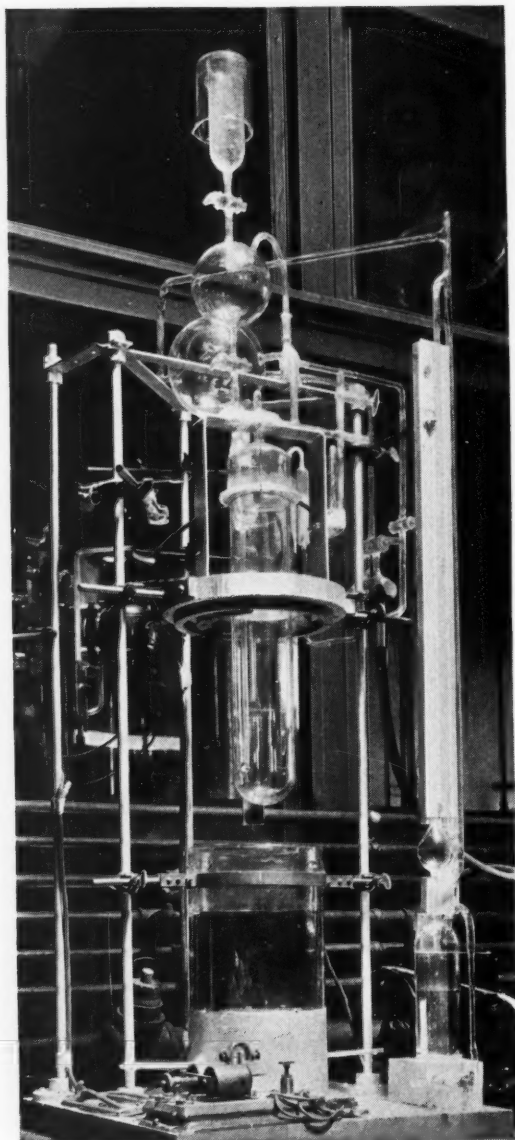
THE MANUFACTURE of coaxial cables for the New York-Philadelphia installation was inspected by M. E. Strieby, J. F. Wentz and O. B. Jacobs at the Point Breeze Plant.

A HIGHLIGHT of the Washington meeting of the American Physical Society held from April 30 to May 2 was the presentation by G. C. Southworth of his paper, *Hyperfrequency Transmission Through Wave Guides* at an evening session held jointly with the Institute of Radio Engineers. A description of this method of transmission was published in the last issue of the RECORD. At the meetings of the American Physical Society the following papers were presented: *Analysis*



*Vacuum tubes which are of no further use are sent by various departments of the Laboratories to the Salvage Department. Here they are dismantled, and the precious metals—platinum filaments and gold contact points—are cut away from their supports and weighed, as shown, by R. C. Fisher. Contact points are returned to Western Electric and the platinum is refined by the metallurgical group in our Chemical Laboratories*

*of Broadening of X-Ray Reflections by Strain*, S. O. Rice; *Energy and Lattice Spacing in Strained Solids*, G. R. Stibitz; *Energy of Lattice Distortion in Hard Worked Permalloy*, F. E. Haworth; *Effect of Annealing on the Properties of Hard-Worked Permalloy*, J. F. Dillinger; *Spontaneous Resistance Fluctuations and the Nature of a Microphonic Carbon Contact and Fluctuations in Carbon Microphones*



*Apparatus for impregnating paper in vacuum, used in connection with dielectric studies by the Chemical Laboratories*

*and Other Granular Resistances*, G. L. Pearson and C. J. Christensen; *Thoriated Tungsten Activation as Revealed by the Electron Microscope*, A. J. Ahearn and J. A. Becker; and *Strain in Galena Crystals Produced by Abrasion*, L. H. Germer.

F. B. LLEWELLYN gave a series of three lectures on *Behavior of Vacuum Tubes at Ultra-High Frequency* at Harvard University during the week of April 20. While in Cambridge he visited the Massachusetts Institute of Technology.

A JOINT MEETING of the American section of the International Scientific Radio Union and the Institute of Radio Engineers, held in Washington on May 1, was attended by a number of engineers from the radio research department. Papers were presented by J. P. Schafer and W. M. Goodall, *Anomalies in the Magneto-Ionic Difference Frequency of the Ionosphere*, and by R. K. Potter and A. C. Peterson, *The Reliability of Short-Wave Radio Telephone Circuits*.

AT THE LAST meeting of the Radio Colloquium for the 1935-1936 season, held at the Holmdel Laboratories, G. C. Southworth and A. P. King discussed *Wave Guides*.

A SYMPOSIUM on electrons, arranged by the Massachusetts Institute of Technology at Cambridge, was attended by C. H. Prescott, J. A. Becker and G. K. Teal.

W. C. JONES visited Hawthorne to discuss with engineers of the Western Electric Company transmission instruments and handset problems. He was also in Washington to confer with the Bureau of Engineering of the Navy Department on similar problems.

G. G. MULLER went to Fort Monmouth, New Jersey, to discuss various telephone instruments with engineers of the United States Army.

V. L. RONCI and W. F. PELL visited the Thompson Gibbs Company at Lynn, Massachusetts, inspecting a seam-welding machine for use in the Laboratories.

ON MAY 8, A. M. Skellett spoke on *The Astrophysics of Transoceanic Telephony* before the Rittenhouse Astronomical Society at the Franklin Institute.



H. FLETCHER attended a meeting of the National Academy of Sciences held recently in Washington.

M. B. GARDNER and H. C. MONTGOMERY are on leave of absence from the Laboratories to help the United States Public Health Service make a special study of the occurrence of defective hearing in different parts of the country. This is part of a general health survey being conducted on a nationwide basis. Hard-of-hearing tests are being made in fifteen cities well distributed geographically and diversified as regards industrialization and other such characteristics that might influence hearing defects. It is planned that by the time the survey is completed approximately 50,000 audiograms, using the Western Electric 2A audiometer, will have been made. Mr. Gardner is aiding in this work at Atlanta, Brunswick, Montgomery, Birmingham, New Orleans, Houston, Dallas and Amarillo, and Mr. Montgomery at New York, Buffalo, Philadelphia, Cleveland, Detroit, St. Louis and Baltimore.

RESULTS OF additional research on selective fading on ultra-short waves were published by C. R. Englund, A. B. Crawford and W. W. Mumford in the May 2, 1936, issue of *Nature*.

J. A. BECKER participated in a discussion held on April 25 at the College of New Rochelle on present opportunities for research in colleges and universities and on how their facilities for research might be augmented.

\* \* \* \* \*

MEMBERS OF THE Laboratories learned with regret of the death of Ray Stokely, with service from December 20, 1917, on April 16. Mr. Stokely graduated from Ohio State University in 1905 and soon became connected with the Automatic Electric Company, where for over ten years he had wide experience in the manufacture, installation and maintenance of step-by-step machine switching equipment. In 1917 he joined the Engineering Department of the Western Electric Company, now Bell Telephone Laboratories, and was responsible for much

of the early pioneering work done on the step-by-step systems developed by the Bell System. During all of the time that he was with the Laboratories his efforts were concerned with this type of equipment and the many patents issued to him demonstrate his ability in the design and development of circuits used in this system. The present method of handling toll calls in step-by-step dial offices was



*Ray Stokely*

designed by him. At the time of his death Mr. Stokely was in the central office switching development group of the Systems Development Department.

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DURING THE MONTH of April K. K. Darrow visited the University of Chicago and Purdue University and attended meetings in Washington of the National Academy of Sciences, the American Physical Society and a conference on molecular physics.

J. SHEA visited Lawrenceville, New Jersey, to install improved equipment in the radio transmitting station.

J. P. HOFFMANN went to Princeton and Philadelphia in connection with the installation of coaxial cable equipment.

J. H. SOLE discussed machine design at Schenectady, diverter pole generators at Cleveland and voltage regulators at Washington, Silver Springs, Maryland and Camden, New Jersey.

B. C. BELLWS, Director of Toll Facilities of the Systems Development Department, completed thirty years of service in the Bell System on the third of May. He graduated at Cornell University in 1906 with the degree of M.E. His telephone experience started the previous summer when, for three months, he was in the student course of the Western Electric Company at West Street. Upon leaving college he entered the Long Lines Traffic Department of the A. T. and T. Company where for six months he was in the student course and for a year and a half in a group engaged in service and force requirements. He then went to St. Louis for six months as division supervisor of the Long Lines, returning to New York to continue his former duties. In 1909 he became Toll Line Engineer.

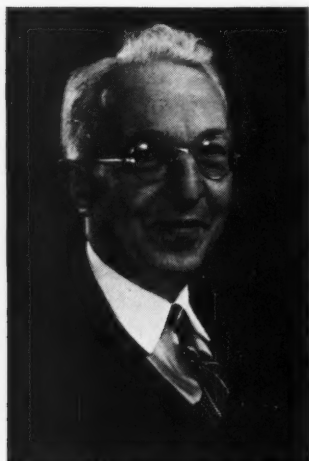
Three years later he joined the Western Union Telegraph Company as Toll Line Engineer and later Traffic Engineer. In November, 1914, he returned to the Long Lines as Service Engineer. While in this position he assisted in the development of the dispatch-operating method designed to get the greatest number of telephone calls over congested facilities. He supervised the operation of this method in San Francisco during the Democratic National Convention in 1920. In October, 1920, he became Division Traffic Superintendent of the Long Lines in Chicago and three years later transferred to the

Illinois Bell Telephone Company as General Supervisor of Toll Traffic.

Mr. Bellows, upon joining the Department of Development and Research of the A. T. and T. Company in 1926 as Toll Systems Facilities Engineer, brought into the Department a wealth of practical traffic operating experience with all types of toll switching equipment. This knowledge and experience of the operating conditions prevailing in areas extending from small communities to large congested districts has been of exceptional value in the proper guidance and coordination of the development of toll facilities for the Bell System. When the D. and R. Department was merged with the Laboratories in 1934, Mr. Bellows became Toll Facilities Engineer in the Systems Development Department and in 1935, Director of Toll Facilities. His work relates to the development of toll switchboards, toll signaling systems and toll maintenance practices, he being responsible for coordinating the operating and transmission requirements on which these developments are based. He also conducts fundamental studies relating to toll switching systems.

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ON THE FIFTEENTH of May, C. W. Keckler completed twenty-five years of continuous service with the Bell System. Before coming to the Bell System he was with the Dean Electric Company of Elyria, Ohio, for six years engaged in circuit engineering and the installation of telephone equipment. In 1911 he joined the equipment engineering group of the Engineering Department of the Western Electric Company at Hawthorne and then a year later transferred to the Northern Electric Company at Montreal on the same type of work. Since 1914 he has been in the Systems Development Department at West Street in charge of a group concerned with the design and development of



*B. C. Bellows*



*C. W. Keckler*

circuits used in manual and panel-dial systems. During the War he was engaged in making available highly important and special telephone facilities urgently required from the Bell System by the U. S. government.

Mr. Keckler contributed much to the development of the panel-sender tandem, the first installation of which was made at East Thirteenth Street in New York and now used in several of the larger cities. As part of this development, the call announcer system was first put into commercial use. He was also responsible for the development of the timing and zoning features in the panel-dial system whereby the subscriber is charged automatically in accordance with the area called and the length of time consumed.

\* \* \* \* \*

JOHN L. HOGG, Transmission Staff Engineer of the wire transmission research group of the Research Department, retired from active service on the first of May. He was graduated by the University of Toronto in 1899 with the degree of A.B. and then, five years later, received his Ph.D. degree from Harvard University. From 1904 to 1906 he was an instructor in mathematics at Harvard. He



*J. L. Hogg*

was head of the Physics Department at McMaster's University, Hamilton, Ontario, from 1906 to 1911, and of the same department at the University of Sas-

*June 1936*

katchewan, Saskatoon, Saskatchewan, from 1911 to 1920.

Mr. Hogg joined the Research Department of the Laboratories on October 20, 1920, and immediately became concerned



E. D. JOHNSON  
*on May 28, completed  
thirty years of service  
in the Bell System*

in an investigation of telegraph transmission to determine permissible distortion in Morse reception. Following this he studied the part that telegraph codes played in the determination of the speed at which communication can be accomplished over wire networks. He was also in charge of the early development of volume control systems to enable speech of varying volumes to be transmitted over lines at more nearly constant volume. This was extended to the reduction in the volume range of speech or music at the sending end of a circuit and the restoration of the original range at the receiving end. Of late he had been making a survey of all known investigations on the behavior of relay contacts for the purpose of determining further research.

During the period from 1926 to 1930, Mr. Hogg was an instructor in the Out-of-Hour course on the theory of telephone transmission. He revised the existing text notes and added considerable material of his own to bring the course up-to-

date. In all of this work he displayed the rare combination of wide technical knowledge and the ability to present this knowledge in a form interesting to and readily grasped by members of the course.

On April 24, a luncheon at Charles Restaurant was given in Mr. Hogg's honor and was attended by over twenty-five of his associates.

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W. BENNETT was in Atlanta to observe the first installation of subscriber-operated time-announcement service.

B. FREILE spent a week at Hawthorne discussing details relating to the manufacture of the new crossbar system.

S. P. SHACKLETON has been elected chairman of the Communication group of the New York Section of the A.I.E.E. for the 1936-1937 year.

PRELIMINARY TESTS of the performance of improved vacuum tubes in telephone repeaters were made by R. L. Case, A. A. Heberlein and H. A. Pidgeon at the Southfields, New York, repeater station.

E. V. GRIGGS attended a hearing before the Board of Appeals in interference proceedings in Washington, and R. Marino was at the Patent Office to interview an Examiner in connection with an application for patent.

L. A. GARDNER went to Washington and Philadelphia to inspect 64-type selective calling equipment.

E. F. WATSON and F. R. McMURRY were in Chicago from April 28 to May 2 to discuss teletypewriter design problems.

TOLL-LINE DIALING problems were discussed by B. C. Bellows, D. L. Moody and R. R. Swain with engineers of the Ohio Bell Telephone Company at Cleveland and Columbus.

J. M. DUNHAM and O. D. GRISMORE were in Charleston, West Virginia, during the week of May 4 in connection with the installation of an oscillograph and a surge recorder at the Turner Substation on the 44-kv. system of the Appalachian Electric Power Company.

A. J. AIKENS and L. HOCHGRAF have gone to La Grange, Indiana, to make tests there and at nearby points in con-

nection with a proposed installation of cable carrier.

J. H. SHUHART went from Phoenixville to Deal to discuss tests of the effects of lightning on open-wire circuits.

E. S. WILCOX has left Lamar, Colorado, and gone to Fort Worth, Texas, to arrange for the making of tests of interference in open-wire circuits.

W. H. TIDD and L. F. STAEHLER have gone to Denver to make measurements of impedance and attenuation on non-loaded toll entrance-cable pairs.

E. D. GUERNSEY and H. B. NOYES have completed the crosstalk, balance and noise induction tests on buried distribution wire which they were conducting at Richmond, Virginia.

H. L. MUELLER attended a storage battery conference at Philadelphia and then went to Washington to inspect a battery installation.

H. M. SPICER made engine vibration tests at Pittsburgh.

J. M. DUGUID and W. S. ROSS tested ringing-power plants at State College, Pennsylvania, and West Hartford, Connecticut, respectively.

C. H. ACHENBACH at Washington and H. T. Langabeer at Detroit discussed power plant design.

R. P. JUTSON observed coaxial-cable power-plant operation at Philadelphia and Princeton.

During MAY ten members of the Laboratories were awarded four-star emblems signifying the completion of twenty years of service in the Bell System. In the Apparatus Development Department, W. L. Betts completed twenty years of service on the first, E. A. Whelan on the fifteenth, Howard Kreft on the twenty-second and V. B. Pike on the twenty-fifth; in the Research Department, E. C. Wentz on the tenth; in the Systems Development Department, R. J. Hopf on the first, H. B. Johnson on the twenty-second, A. C. Gilmore on the twenty-fourth and F. A. Muccio on the thirty-first; and in the Plant Department, John Cummings on the second.



# A New Power Amplifier of High Efficiency

By W. H. DOHERTY

*Radio Development*

THOSE who are accustomed to operating vacuum tubes at the low power levels employed in wire transmission or in radio receiving systems are frequently startled to learn of the extremes to which one must resort in the operation of power amplifier tubes in radio transmitters. The transmitting tube, far from being operated over a small and linear part of its characteristic, is subjected to large alternating grid voltages which cause the plate current to be zero over approximately one-half of the radio-frequency cycle, and frequently to reach the saturation value determined by filament emission on the other half-cycle, with accompanying large grid currents. This extreme mode of operation makes possible much larger power outputs than could be obtained if operation were confined to the linear part of the tube characteristic.

Figure 1 shows the circuit of a simple form of the conventional radio-frequency power amplifier, in which two tubes are connected in parallel and coupled to the transmitting antenna. The coupling circuit is so tuned as to be equivalent to a pure resistance load of the desired value over the relatively narrow transmission band occupied by the carrier and the side-frequencies due to modulation, while for frequencies much lower or much higher than the carrier, the impedance of the circuit is very low. Hence, although the radio-frequency plate current wave contains large harmonic

components due to the extremely non-linear operation of the tubes, only the fundamental component encounters any appreciable impedance, so that the plate voltage wave is very nearly sinusoidal. The power delivered by the tubes to the circuit is therefore almost entirely at the fundamental frequency. High-quality amplification of a modulated wave then requires merely that the fundamental component of the plate current be proportional to the radio-frequency grid voltage. It turns out that if the tubes are biased nearly to the cut-off point, so that plate current flows only during the positive half-cycle of the alternating grid

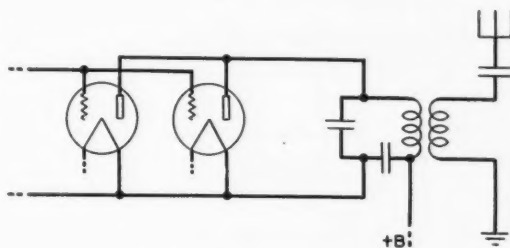


Fig. 1—Radio-frequency power amplifiers are coupled to the load by tuned circuits which present a very low impedance to the tubes at harmonics of the carrier frequency

voltage, a close approximation to this requirement of proportionality is readily obtained.

Under these conditions, which are represented in Figure 2, most of the plate current flows while the plate potential is near its minimum value, and if this minimum value is suffi-

ciently low—i. e., if the amplitude of the plate voltage wave is sufficiently great—the power lost in the tubes, which is proportional to the product of instantaneous plate voltage and current, will be small, and the effi-

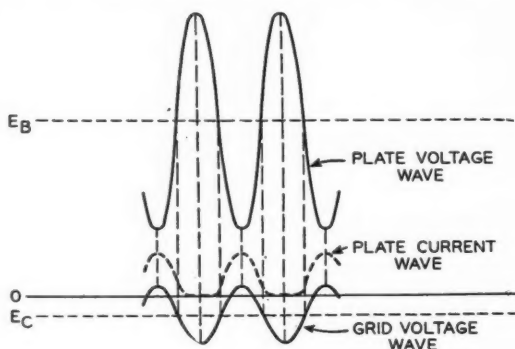


Fig. 2—Most of the plate current of a power amplifier flows while the plate potential is in the vicinity of its minimum value, so that the tube loss can be made small by a plate voltage swing of large amplitude

ciency correspondingly high. The efficiency is, in fact, very closely proportional to the amplitude of the plate voltage swing. By permitting the plate voltage to swing down to a value as low as 10 or 15 per cent of the applied d-c plate potential, large power outputs may be obtained at an efficiency of 60 to 70 per cent; but unfortunately such large amplitudes correspond only to the peaks of modulation, and since these peaks at 100 per cent modulation have amplitudes of twice the carrier amplitude, the plate voltage swing for unmodulated carrier must not be more than half of its peak value.

The efficiency of the conventional power amplifier, then, is but 30 to 35 per cent when the carrier is unmodulated, and only slightly more for the average percentage modulation of the usual broadcast program. An efficiency of 33 per cent means that the d-c power supplied to the plate

circuit of the amplifier must be about three times the carrier output, and two-thirds of this input power has to be dissipated at the anodes.

With power levels of 50 kilowatts and higher becoming almost commonplace in radio broadcasting, it has become very important to find means for increasing efficiency to reduce the cost of power. Since early in 1934 a succession of tests have been conducted at the Whippany Laboratory on a new power amplifier circuit in which the usual practice of dividing the load equally between the tubes at all times was discarded. The idea was conceived that by obtaining the power from a reduced number of tubes up to a certain point—in particular the carrier output—these tubes could be operated at this point at their maximum plate voltage swing, and consequently at high efficiency; then if the remaining tubes were brought into action in a certain manner they would not only contribute to the out-

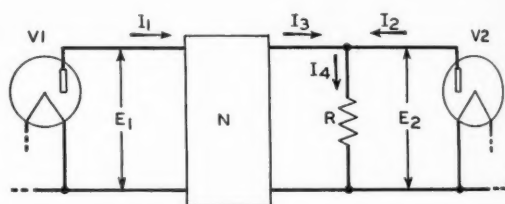


Fig. 3—In the high-efficiency circuit, an impedance-inverting network, *N*, is inserted between one of the tubes and the load

put, but would so change the operating conditions for the original tubes as to permit the latter also to increase their output power without having to increase their output voltage.

Figure 3 shows schematically the method of connecting the tubes to the load in the new high-efficiency circuit. *V1* and *V2* are two tubes that in the conventional amplifier might

have been connected in parallel with a circuit whose impedance, for the fundamental frequency, may be represented by the resistance  $R$ . In the new circuit a network  $N$  is interposed between  $R$  and  $V_1$ , the tube which is to deliver the carrier power. This network is the equivalent of a quarter-wave transmission line, and like such a line has the interesting property that its impedance as measured at one end is inversely proportional to the impedance connected at the other end.

For all values of grid excitation from zero up to the carrier level,  $V_2$  is prevented by a high grid bias from having any plate current, and the power is obtained entirely from  $V_1$ . The network  $N$  is so designed as to present to  $V_1$  an impedance so high as to require this tube to operate at nearly its maximum possible radio-frequency plate voltage swing in order to deliver the carrier power. The efficiency of the amplifier at the carrier output is accordingly high, and may be from 60 to 70 per cent.

If we were to plot the current in

the load impedance  $R$  against the radio-frequency voltage applied to the grids of the tubes, as in Figure 4, the curve would be essentially linear up to the carrier point  $A$  and then, if  $V_2$  were not allowed to come into action, would flatten off along a path  $AB$  because the plate voltage swing on  $V_1$  had attained its maximum value.

By permitting  $V_2$  to begin coming into play at point  $A$  we obtain a two-fold action:  $V_2$  not only contributes power to the load, but in coming into play in parallel with  $R$  it effectively

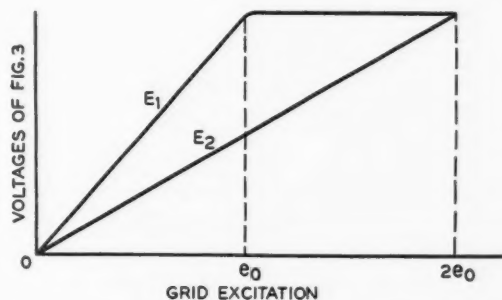
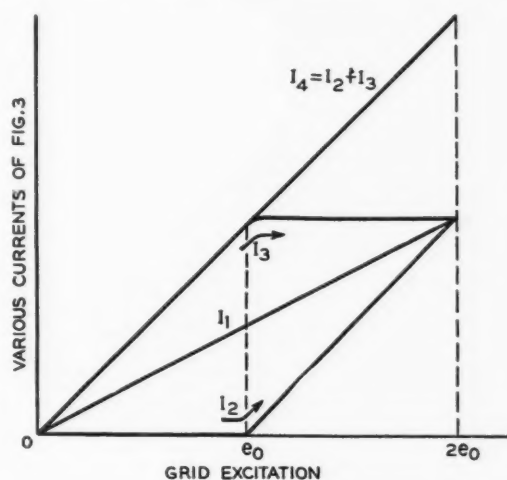


Fig. 5—(Above)—The current  $I_2$ , furnished to the load by tube  $V_2$ , supplements  $I_3$  to make the total load current linear with respect to the grid input voltage. (Below)—As the grid excitation is modulated about its carrier value  $e_0$ , the plate potential of tube  $V_1$  does not respond to the positive half-cycles of modulation, since it has reached its maximum value at the carrier output

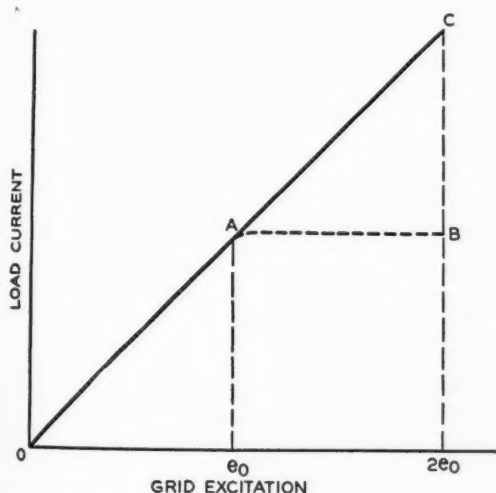


Fig. 4—If the second tube were not permitted to come into action at the carrier excitation  $e_0$ , the load current could not increase, and so would follow the path  $OAB$

increases the impedance in which the network  $N$  is terminated. This increase in terminating impedance, by virtue of the inverse characteristic of this type of network, results in a decrease in the impedance presented to  $V_1$ , so that the radio-frequency plate current, and hence the power output, of  $V_1$  may increase without any increase in its alternating plate voltage, which was already a maximum at point A. As the grid excitation on the tubes increases beyond its carrier value  $e_0$ ,  $V_2$  contributes more and more power to the circuit and thereby permits  $V_1$  also to supply more power, until, at point C, which corresponds to the instantaneous peak of a completely modulated wave, half of the power in  $R$  is being contributed by  $V_2$ . The network  $N$  is at that instant effectively terminated in  $2R$  ohms instead of the original  $R$  ohms, and the impedance presented to  $V_1$  is half of its original value,

permitting  $V_1$  to deliver twice its original output power with no increase in its output voltage. The total power in the load, then, at the peak of modulation is the required value of four times the carrier power, corresponding to an increase in load current to twice its carrier value.

It is a characteristic of networks having the impedance-inverting property of network  $N$  that a definite current at either pair of terminals is associated with a definite voltage at the other pair of terminals, entirely without regard to the terminating impedances. From this rather remarkable property we may deduce that if the output voltage  $E_1$  of tube  $V_1$  is linear with respect to the grid excitation up to the carrier excitation  $e_0$  of Figure 4, and then remains constant up to the peak excitation  $2e_0$ , then the current  $I_s$  fed into the load from network  $N$  behaves similarly, as shown in Figure 5(a); whence,

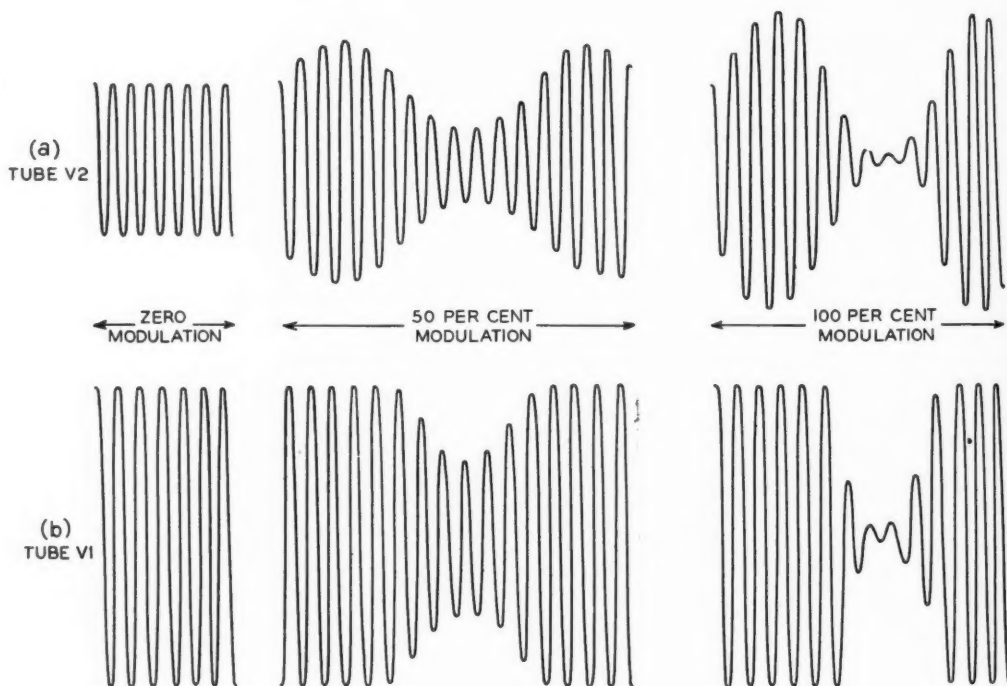


Fig. 6—Cathode ray oscillograms of the plate potentials of the tubes



in order to have the total load current  $I_4$  linear with respect to grid excitation, the current  $I_2$  fed into the load from tube  $V_2$ , which is zero at the carrier point, must rise linearly beyond this point and be equal to  $I_3$  at the peak of modulation.

From this same property of network  $N$  we also deduce that if the voltage  $E_2$ , across the load and the

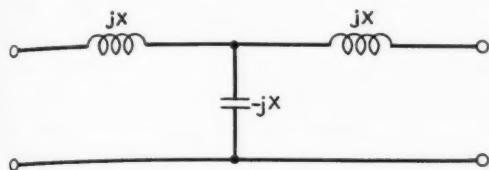


Fig. 7—A section of simple low-pass filter at 0.7 times the cut-off frequency consists of three equal reactances, and has a 90-degree phase shift together with the desired impedance-inverting characteristic

second tube, is linear with respect to grid excitation, then the current  $I_1$  fed into network  $N$  by tube  $V_1$  must also be linear. Figures 5(a) and 5(b) therefore give the complete picture of the conditions existing at the plates of the two tubes for all values of radio-frequency grid input voltage to the amplifier, and the behavior of each tube during the modulation cycle may be studied by considering the grid excitation to vary at audio frequency about its average value  $e_0$ , to the extent corresponding to the percentage modulation.

When samples of the radio-frequency plate potentials on the two tubes during modulation are viewed on the screen of a cathode ray oscilloscope, the patterns are of the shape shown in Figure 6. Patterns (a) represent the envelope of the plate potential of  $V_2$ , which, being directly associated with the load, is required to be sinusoidal when the modulating signal is a pure tone. Patterns (b)

show the envelope of the plate potential of  $V_1$ , which, though sinusoidal over the negative half of the modulating cycle, is twice as high as that of  $V_2$  over this range, and being unable to increase appreciably beyond its carrier value, remains flat during the upper half of the cycle of modulation.

The network  $N$  employed to obtain the impedance inversion may be one of a number of networks of which an example is given in Figure 7. They always have a 90-degree phase shift, which means that the plate potentials on the two tubes are always in quadrature. This requires the insertion, in the grid circuit of one or the other of the tubes, of another 90-degree network in order that both tubes may be excited from the same source. The complete amplifier then assumes one of the forms indicated in Figure 8.

The numerous tests conducted on the high-efficiency amplifier at var-

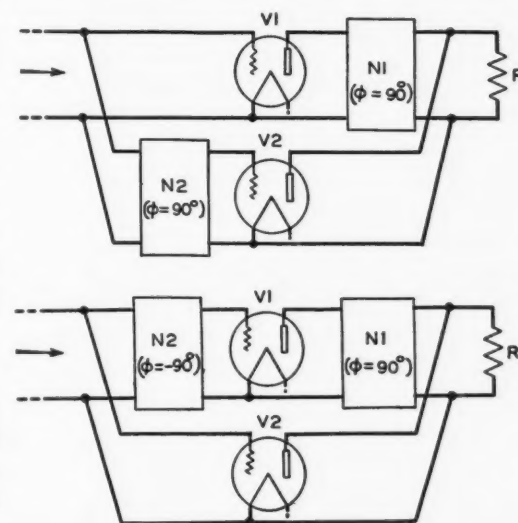


Fig. 8—With a 90-degree phase shift in the plate circuit of one tube, a compensating phase shift must be inserted in the grid circuit of one of the tubes so that both tubes may be excited from the same source

ious power levels have been uniformly successful, and the new circuit is being incorporated in the new high-power broadcasting equipment of the Western Electric Company. The overall efficiency obtained in the tubes and output circuits is 60 per cent for unmodulated carrier and a few per cent higher with complete modulation. This represents a reduction in the plate power consumption of the final stage of a radio transmitter by nearly a factor of two, as compared with the power required by an amplifier of the conventional type. A 50-kilowatt amplifier, for example, with 33 per cent efficiency would require a d-c plate input of 150 kilowatts, of which 100 kilowatts would be dissipated at the anodes of the water-cooled tubes. With the new circuit the power input for unmodulated carrier is 83 kilowatts, and the dissipation accordingly only 33 kilo-

watts, permitting a considerable saving in the water cooling system as well as in power requirements. These items are of great importance in modern broadcasting where the cost of apparatus and power constitutes a large part of the operating expense.

By the application to radio transmission of another Laboratories development, the feedback principle\* of H. S. Black, to reduce the effects of non-linearity in the amplifier characteristics, the new high-efficiency equipment has been made to perform with a quality of transmission which satisfies the most rigorous requirements of high-fidelity broadcasting.

Finally, the new circuit, being purely an amplifying scheme, can be applied to special types of transmission, such as the single-sideband transmission employed in the transoceanic service of the Bell System.

\*RECORD, June, 1934, p. 290.

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### *Vail Medal Awards for 1935*

For the second time since the establishment, in 1920, of the Theodore N. Vail Memorial Fund, special recognition was given to the entire personnel in an area of a telephone company by the National Committee of Award. A special plaque has been awarded to the employees of the Mountain States Telephone and Telegraph Company at Helena, Montana, "for outstanding performance, when, during the month of October, 1935, a succession of earthquakes of varying intensity and extending over a period of about three weeks caused damage to telephone plant and other property and placed an especially heavy demand upon the entire telephone organization. Through the courageous action and splendid cooperation of employees of all departments, telephone service was maintained,

crippled plant was restored to service and telephone service was available continuously to rescue and relief agencies, greatly accelerating their activities."

In the report of the Committee for 1935 announcement was also made of the award of two silver medals, each accompanied by \$250, to the following:

To Ruby C. Bahr, a Telephone Operator of the Community Telephone Company, Fairfield, Wisconsin, "for alertness, initiative and prompt and intelligent action which led to the apprehension of a dangerous criminal."

To Mamie Inez Pitts, a Telephone Operator of the Southern Bell Telephone and Telegraph Company, Pontotoc, Mississippi, "for courage, resourcefulness and loyalty to public service, despite grave personal danger, during a tornado."

# X-Ray Diagnosis for Telephone Apparatus

By LESTER E. ABBOTT

*Telephone Apparatus Development*

**X**-RAY technique has been found extremely helpful in a number of engineering fields. One of the most obvious advantages is that destruction of the object examined is not required to discover its internal condition. This has made x-ray examination a valuable engineering tool for detecting hidden flaws and defects in metallic objects.\* Another useful field for x-rays, particularly in telephone work, is for the examination of assembled apparatus suspected of containing defective wiring or misaligned parts. Such apparatus is often housed in a sheet steel case of appreciable thickness, and may consist of condensers, inductances, resistances or a combination of these depending upon the particular type of telephone apparatus considered. To complicate the problem further, these assemblies are frequently sealed in position by completely filling the space around the parts with a potting compound. Thus the x-ray procedure must result in recognizable differences on a photographic film between assembled parts which may be composed of combinations of metals and non-metallic materials, all of different dimensions, and completely embedded in a potting compound.

This objective is attained by taking advantage of the differences in absorbing power for x-rays of the several parts of the apparatus photographed. The image produced on the x-ray film is therefore a shadow picture,

the gradations in the shading of which depend upon the variations in the x-ray absorption of the different materials and the thickness of the parts. It is possible to draw an analogy between the taking of a photograph and the making of an x-

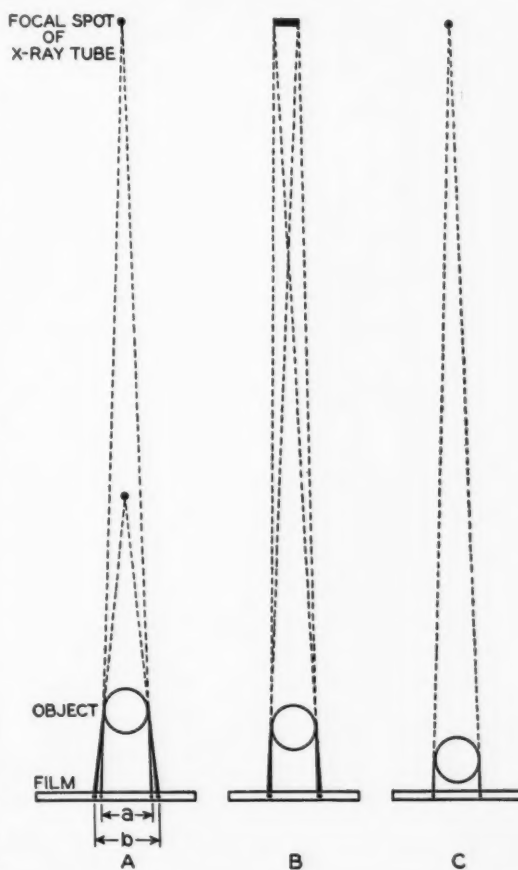
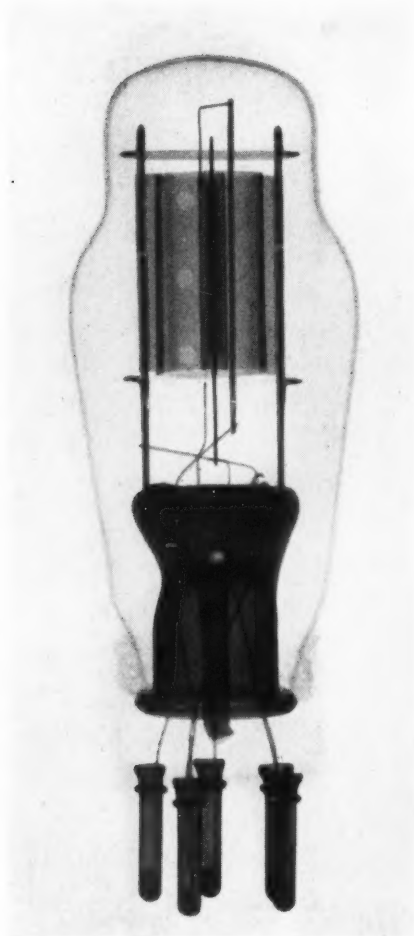


Fig. 1—The sharpness of an x-ray photograph improves as the distance of the x-ray tube from the object increases and the size of the focal spot of the tube decreases; also as the distance from the object to the photographic film decreases

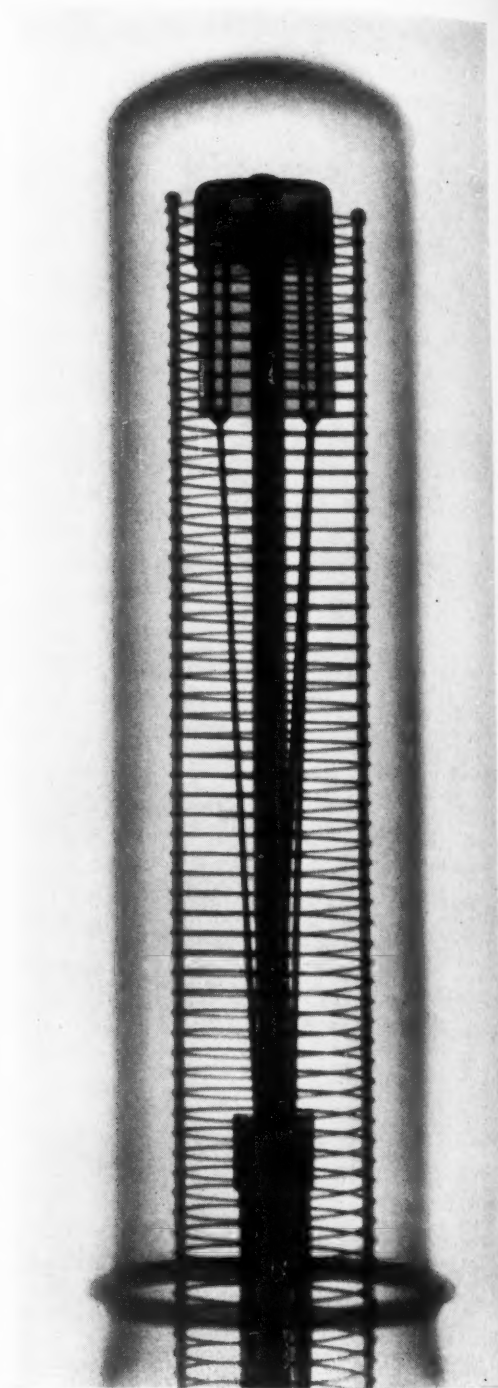
\*RECORD, November, 1933, page 72.



*Fig. 2—The filament and grid assembly of a completed vacuum tube can be inspected with x-rays*

ray picture, but there is a fundamental difference because no method of focusing x-rays is known, so that sharp definition can be obtained with them only if their source approximates a point.

Since the focal spot of an x-ray tube is usually an oval of definite size with the long dimension not exceeding one-quarter of an inch, the only means of controlling the sharpness or definition of an x-ray negative is by increasing the distance which separates the tube from the object under examination. This results in



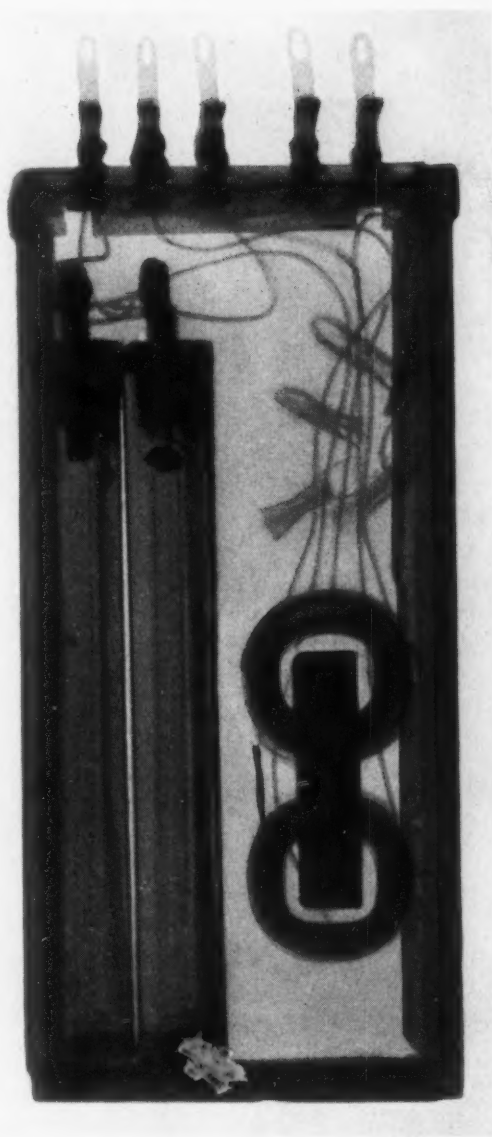
*Fig. 3—X-ray photographs through the metal jacket of transmitter tubes disclose the parts within*

the focal spot acting more nearly as a point source. The projected image



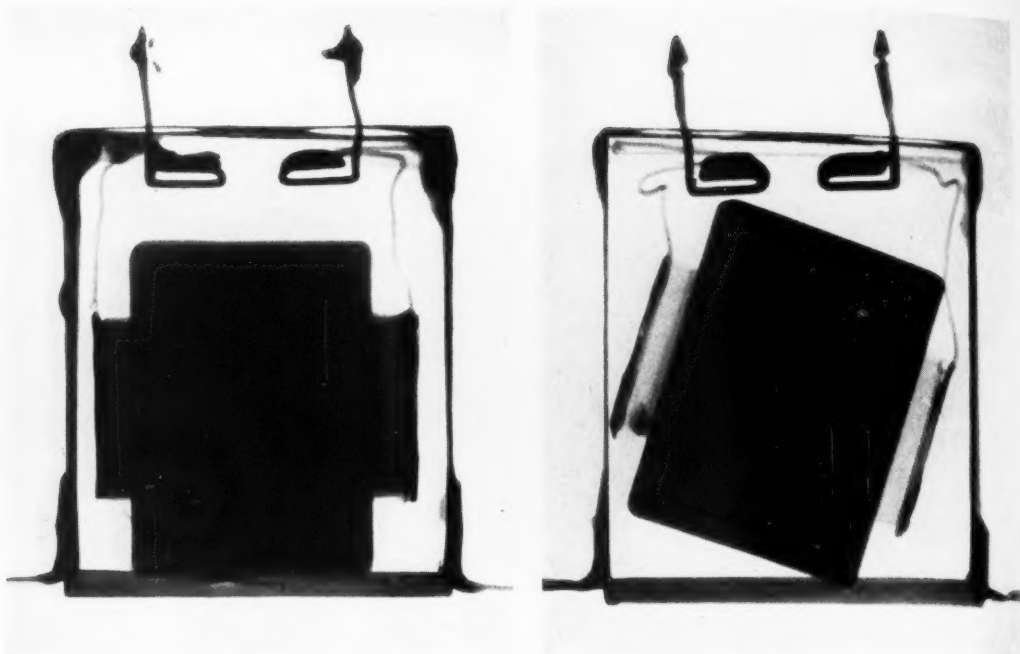
of an assembled object is more nearly correct in dimensions when a long x-ray source-to-film distance is used, as may be seen by comparing *a* and *b*, in Figure 1, A. In B of Figure 1 is shown the spreading of the projected image due to the use of an x-ray tube having a large focal spot. The position of the objects in the apparatus under examination in relation to the position of the x-ray film also affects the definition of the x-ray negative. The sharpness of the image decreases as the distance of the film from the object increases because of x-ray scattering. This is suggested in Figure 1, by comparing A, case *a*, with C. In practice a source-to-film distance of from twenty-four to thirty-six inches is generally used to obtain satisfactorily sharp images. Additional sharpness might be had—especially if the assembly under examination has considerable depth—by using even greater source-to-film distances, but the exposure time required would be greatly increased, since the inverse-square law applies to x-ray radiation, and an exposure at forty-eight inches takes four times that required for a twenty-four-inch source-to-film distance.

The x-ray method of non-destructive examination has been applied successfully to a number of telephone problems of widely different types. In vacuum tube development work, for example, it is desirable to check the filament and grid assembly before test, and to check any changes which occur during test or after failure. Since the filament and grid assembly is usually completely blocked from visual examination by the plate, x-ray examination is employed to obtain the desired information. A small tube of the glass-enclosed type, in which the position of the various elements may be clearly seen, is shown in Figure 2.



*Fig. 4—An apparatus assembly embedded in pitch can be inspected with x-rays*

Larger types of tubes, transmitters for instance, have the grid and filaments completely encased in a metal jacket which acts as the plate. Such tubes are inspected easily by x-rays, and a uniform technique for examination makes it possible to check fairly small changes in the position of the elements by comparison of radiographs taken several months apart.



*Fig. 5—The cause of apparatus failure can often be determined quickly from an x-ray photograph*

Usually in these inspections two radiographs are taken at right angles to each other so that the information obtained may be complete. Figure 3 is a typical radiograph of this type.

When an assembly consists of condensers, coils and resistances, embedded in a potting compound, there is always a possibility of misalignment of the parts, or of short circuits caused by the resistances or lead wires being sealed against the sides of the container. In Figure 4 is shown one of two views of an assembly of this type, which was x-rayed to determine the position of the small resistances. It should be noted that the detail obtained is such that even the voids present in the potting compound are visible.

When apparatus is received for test in connection with an engineering complaint, x-ray examination may often furnish definite proof of the cause of failure, and in addition pro-

vide a permanent record of the faulty condition on the x-ray negative, prints of which may be included in the engineer's report. Figure 5 shows views of two condenser units which were x-rayed in connection with an engineering complaint investigation. The condenser on the left has a broken wire, and the other was considerably misaligned when assembled, which greatly increased the possibility of trouble developing in service.

To sum up the advantages of the x-ray method of examining assembled apparatus—it is a non-destructive test; it may be repeated at regular intervals on apparatus under life or service test and thus reveal any internal changes of a physical nature which occur; it is an excellent means for checking the alignment of parts in a complicated assembly; and it furnishes a permanent record of the condition of the apparatus examined, at a known date.



## An Acoustic Resistance Meter

By T. J. POPE

*Transmission Instruments Development*

**D**URING the early youth of electrical science, the behavior of electricity in a circuit was likened to the flow of water through a system of piping, and in fact such analogies are still used in pre-college instruction. Not only was the analogy drawn, but many of the terms now used to describe electric circuit phenomena such as "flow," "current," "pressure," and "resistance" are taken directly from fluid dynamics. With the extensive study of acoustics in more recent years, the borrowing of terms has taken a reverse direction, and many of the more complex conceptions of electric circuit theory such as impedance, resonance, and capacitance have been taken over by the science of acoustics, which is one branch of fluid dynamics. In many ways the analogy between acoustic and electric systems is very close, as is brought out in one respect by the acoustic resistance meter employed

for many purposes in studies of sound.

A common way of determining the value of an electrical resistance is to measure the voltage drop across it while it is carrying a known current. From Ohm's Law the resistance is then equal to the quotient of the voltage by the current. The circuit would be as in A of Figure 1. A rheostat permits the current to be set at some convenient value, which is read on an ammeter, and the drop across the resistance is read on a voltmeter. In the fluid analog, shown at B, a pump replaces the battery, and a valve, the rheostat; and suitable flow and pressure meters give the current flowing and the pressure drop across the resistance, indicated by an enlarged section of pipe filled with obstructing material, such as steel wool. If the current flow is measured in cubic centimeters per second and the pressure drop in dynes per square centimeter, the resistance will then be in

what is usually called acoustic ohms.

The ammeter in 1A consists of a small known resistance with a voltmeter connected across it with its scale marked in the values of voltage divided by the fixed resistance, or current flowing, since  $V \div R = I$ . A more complete representation of the circuit would thus be that shown in 2A, which is similar to 1A, but with the ammeter replaced by a known resistance shunted by a voltmeter. The corresponding fluid circuit is shown in 2B, where a manometer and a resistance replace the flow meter of 1B. The arrangement of 2B, when air is the fluid, is an acoustic resistance meter to measure the acoustic or mechanical resistance of the piece of apparatus inserted at x. But why call this acoustic resistance? The term acoustic applies to sound, while no sound is involved in this apparatus at

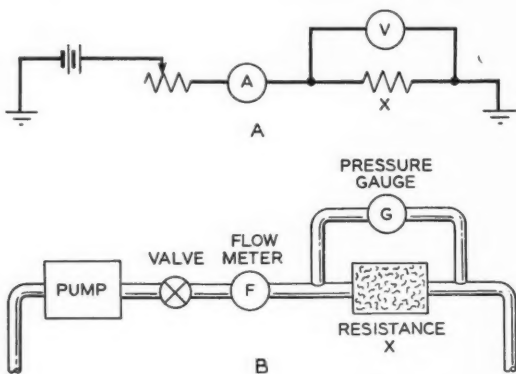


Fig. 1—A—a simple arrangement for measuring electrical resistance; B—an equivalent method for measuring the resistance to fluid flow

all, at least none that is desired or measured. A flow of air, and an air resistance are what is measured. The reason for and justification of the term, however, is not hard to find.

Sound is caused by air in vibration, and its electrical analog is an alternating current. It is found that the

opposition to the flow of an alternating current, which is called impedance, is not constant, but varies with frequency. An impedance has two components: a reactance, which may be either positive or negative and

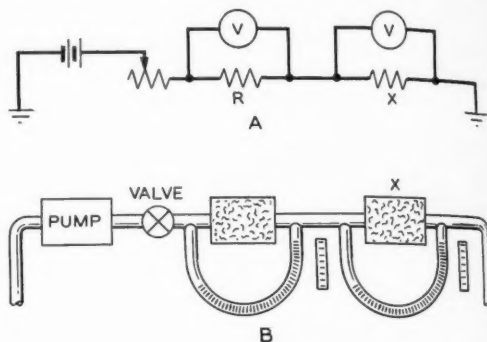


Fig. 2—The ammeter of Figure 1 consists of a fixed resistance and a voltmeter, as indicated at A. In the fluid circuit, B, this corresponds to a fixed resistance and a manometer

which varies in value with the frequency; and a resistance, which for any single element is approximately independent of frequency. At zero frequency (direct current) the impedance is equal to the resistance because the reactance component becomes zero.

In the acoustic analog there is a closely similar set of factors: an acoustic reactance, which becomes zero at zero frequency, and an acoustic resistance which does not. An acoustic impedance at zero frequency is the acoustic resistance, but it is here that the apparent paradox enters, because sound at zero frequency is no longer sound, but a steady flow of air. Thus an arrangement like that of Figure 2B, which measures resistance to a steady flow of air, really measures an acoustic resistance.

The design of transmitters, receivers, handsets, and all acoustic apparatus requires that the acoustic re-



actances and resistances of all parts be known. While apparatus for measuring acoustic impedance is available, it is more elaborate than the acoustic resistance meter, and more time is consumed in making a measurement. For many purposes, moreover, a measurement of resistance alone is sufficient. Often it is desired to compare the acoustic impedances of pieces of apparatus which have the same general form of impedance curve. In such cases a measurement of resistance alone, which establishes the point at which the curve crosses the axis of zero frequency, is sufficient to indicate the relative values of the impedances. Also, it is sometimes possible to calculate the values of reactance, so that a measurement of resistance alone is sufficient to permit the impedance to be determined. A simple acoustic resistance meter is thus very useful, and several of them are in use in the Laboratories.

One form is shown in use in the photograph at the head of this article. Its general arrangement is illustrated in more detail in Figure 3. A compressed air supply is admitted through a valve at the extreme left and passes through two resistances with a by-

pass valve between them. This arrangement permits a fine control of air pressure at the input to the meter proper. The capillary tube has a very small bore and serves as the fixed resistance for measuring flow. A manometer, bridged across it, measures the pressure drop, which—divided by the resistance of the tube—gives the actual flow in centimeters per second. The air then passes through the resistance under test. A second manometer measures the pressure at this resistance. The scale of this manometer is marked along an inclined portion of the tube to permit accurate measurement of very small pressures. A rubber tube connection allows the adjusting reservoir to be raised or lowered so as to bring the level of the liquid in the inclined tube to the zero point of the scale.

With the instrument shown, and a flow of 5.1 cc per second, one centimeter on scale F will correspond to 10 ohms resistance. To make a measurement it is necessary only to raise or lower the reservoir to adjust the zero position of scale F, and then to adjust the flow by the valves until the proper reading on scale A is obtained to indicate 5.1 cc per second. The resistance

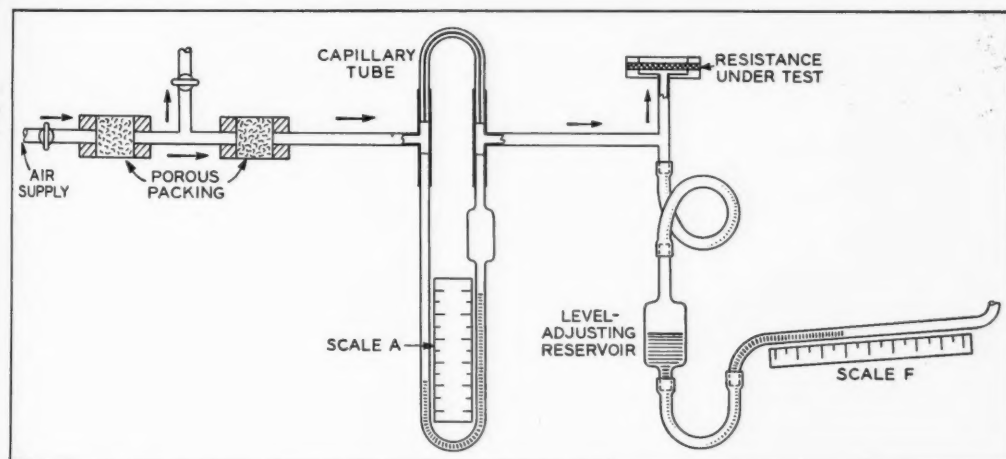


Fig. 3—One form of acoustic resistance meter used in the Laboratories

may then be read directly on scale F. The instrument is adapted to measuring the acoustic resistance of almost any type of element from a piece of fabric, as in Figure 3, to a complicated piece of apparatus. An application to the measurement of microphone parts

has already been mentioned in the RECORD.\* The arrangement shown in the photograph at the head of this article employs two fixed resistances (capillary tubes), either of which may be connected into the circuit.

\*RECORD, May, 1932, p. 320.



*Dr. H. B. Williams, Dalton Professor of Physiology and Executive officer of the Department of Physiology of the College of Physicians and Surgeons of Columbia University, and Dr. B. G. King, Instructor in Physiology at Columbia University, who coöperated with L. P. Ferris and P. W. Spence of Bell Telephone Laboratories in the investigation of the effect of electric shock on the heart reported in this issue of the Record.*

## Contributors to this Issue

E. L. OWENS graduated from Virginia Polytechnic Institute in 1924 with the B.S. degree in Electrical Engineering. He then entered the Engineering Department of the Western Union Telegraph Company and remained with them for some five years. In 1929 he became a member of the Technical Staff of the Laboratories. Here, with the Radio Development Department, he has been engaged in the development of speech input equipment for radio broadcasting transmitters.

L. P. FERRIS received the B.A. degree from the University of Colorado in 1908 and the B.S. degree in electrical engineering from M.I.T. in 1911. Immediately thereafter he joined the Engineering Department of the A. T. and T. Company, his first assignment being the capacity unbalance testing of the first cable laid between Philadelphia and Washington. After about two years in transmission engineering he was sent to California where he was engaged for five years in a joint investigation with power engineers of inductive interference with communication circuits by power circuits. In 1919, when the Department of Develop-

ment and Research was formed, his work in that department included carrier and telegraph transmission problems. In 1920 his work was transferred to inductive interference, crosstalk and measuring devices. Later when his organization was transferred to the Laboratories he became Inductive Coördination Engineer. Questions as to the effect of foreign voltages on telephone circuits arose many times in connection with Mr. Ferris' work and led to the joint study of electric shock with Dr. H. B. Williams and Dr. B. G. King, of Columbia Medical School, and P. W. Spence, of the Laboratories, which is summarized in this issue of the RECORD.

P. W. SPENCE joined the Engineering Department of the American Telephone and Telegraph Company in 1914 and worked for a year on safety codes. He then severed his connection with the company temporarily to study at Columbia University where he received the B.S. degree in 1918 and that of E.E. in 1921. In the latter year he returned to the American Telephone and Telegraph Company and engaged in studies of inductive interference in the Long Lines Department.



*E. L. Owens*



*L. P. Ferris*



*P. W. Spence*



*L. E. Abbott*



*J. B. DeCoste*



*W. H. Doherty*

From 1922 to 1927 he was with the Operations Department, working on problems in broadcasting development, new services and patent licensing. Since 1927 he has been largely occupied with the studies on the effects of electric shock which are reported in this number of the RECORD.

L. E. ABBOTT was graduated from the Brooklyn Polytechnic Institute with the degree of M.E. in 1928, and obtained his M.S. degree from the same institution in 1931. As a member of the Materials group he worked on various problems connected with the physical properties of metals until 1930, when he began his present work. This is concerned with the use of welding in telephone apparatus fabrication, and the application of X-ray technique to telephone problems.

J. B. DECOSTE entered the Commercial Department of the Laboratories in 1928. In the same year he was transferred to the Chemical Research Department where he has been engaged in the development of organic finishes, synthetic resin plastics and resinous adhesives. In 1933 he received a B.S. degree in chemical engi-



*T. J. Pope*

neering from Cooper Union. W. H. DOHERTY received the B.S. degree in electric communication engineering from Harvard University in 1927, and the M.S. degree in engineering in 1928. He spent a few months in 1928 with the Long Lines Department in Boston as a technical employee and then became a research associate with the radio section of the Bureau of Standards, where he engaged in a study of radio wave phenomena. In June, 1929, he joined the Radio Development Department of the Laboratories where he has been engaged ever since in the development of high-power transmitters for transoceanic radio-telephony and broadcasting.

T. J. POPE received the B.S. degree from the University of Illinois in 1927 and at once joined the Technical Staff of the Laboratories. Here, with the Research Department, he has worked chiefly in the field of acoustics, devoting a large part of his time to the study of acoustic impedance and its measurement. While with the Laboratories he has also studied at Columbia University, and received his M.A. degree in 1934.